EXHIBIT 15

IN THE UNITED STATES DISTRICT COURT
FOR THE DISTRICT OF DELAWARE

BRIDGESTONE SPORTS CO. LTD., AND BRIDGESTONE GOLF, INC Plaintiff, v. ACUSHNET COMPANY Defendant.	Case No. 05-132(JJF)
ACUSHNET COMPANY Counterclaim-Plaintiff, v. BRIDGESTONE SPORTS CO. LTD.,, AND BRIDGESTONE GOLF, INC Counterclaim-Defendant.	

EXPERT REPORT OF EDWARD M. CAULFIELD, Ph.D., P.E.

REPORT OF EDWARD M. CAULFIELD

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I. INTRODUCTION

1. My name is Edward M. Caulfield, Ph.D., P.E. I am President and Chief Technical Officer of Packer Engineering, Inc, a multi-disciplinary engineering consulting and technical services company with locations in Naperville, Illinois, Cincinnati, Ohio, Washington D.C., and Ann Arbor, Michigan. Packer Engineering offers a wide range of engineering, testing, and analysis services, including extensive work in the mechanical engineering and materials engineering fields.

2. I have been retained in this matter to evaluate golf balls manufactured by the Defendant, Acushnet, in connection with US patents 5,262,652; 5,553,852; 5,743,817; 5,782,707; 5,803,834; 6,634,961; and 6,679,791 (held by Bridgestone Sports Co,. LTD) in conjunction with an investigation of patent infringement issues. Packer Engineering is charging my normal hourly rate of $475.00/hour for my time spent in this matter and neither Packer Engineering. nor I have any financial or other interest in the outcome of this case or in any of the parties to this action.

II. QUALIFICATIONS

3. I have a Ph.D. in Theoretical and Applied Mechanics, an M.S. in Theoretical and Applied Mechanics, and a B.S. in Mechanical Engineering in Machine Design.

4. I am a member of Sigma Xi (Scientific Honorary Society) and have published and/or presented numerous technical papers. These papers are listed in my curriculum vitae (CV) attached as Exhibit EX-1. I have also presented numerous seminars to audiences with a wide range of interests, a list of which is also set forth in Exhibit EX-1.

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5. I am a Professional Engineer registered in the State of Illinois and in the State of Florida, and I am also affiliated with the following professional organizations:

    American Society of Mechanical Engineers
    American Society of Testing and Materials
    Society for Experimental Mechanics
    American Association for Automotive Medicine
    Society of Automotive Engineers
    Illinois Society of Professional Engineers
    National Society of Professional Engineers

6. Before joining Packer Engineering in 1979, I was an Assistant Professor in the Department of Mechanical Engineering at the University of Illinois and taught courses in dynamics, vibration, materials science and the design of machinery.

7. In my educational background and duties at Packer Engineering, I have developed a thorough understanding of the properties and behavior of materials and mechanical design issues. My personal practice involves the application of materials engineering and mechanical engineering principles to design review and evaluation, failure analysis, patent infringement analysis, accident investigation and reconstruction, and testing. Since joining Packer Engineering in 1979, I have consulted for a wide range of industrial clients, including golf equipment manufacturers, farm machinery and industrial equipment manufacturers and automobile makers.

8. Based on my education, training, knowledge of the literature, and professional experience, I am fully competent to testify regarding the subject matters of, among other things, the material properties and material property testing of golf balls including those material properties described and claimed in the patents at issue in this matter.

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9. Additional details regarding my qualifications and background can be found in my attached CV and Rule 26 list of cases in which I have testified (Exhibit EX-1)

III. MATERIALS CONSIDERED

10. In addition to information as a result of my general background and experience, I have reviewed and asked my engineering staff to help in the review of materials relating to the patents-in-suit as listed in Exhibit EX-2. Exhibit EX-3 contains the testing standards utilized in the test protocols for this investigation.

IV. METHODOLOGY

11. This investigation included the evaluation of a number of golf balls manufactured by Acushnet Company for their material properties and performance as related to the patents at issue in this matter. The Acushnet golf balls evaluated in this study included Titleist Pro V1, Titleist Pro V1x, Titleist Pro V1 Star, Titleist DT So/Lo balls, Titleist NXT, Titleist NXT Tour and Pinnacle Exception golf balls. All balls included in this investigation were obtained from standard retail outlets.

12. A number of evaluations related to the patents at issue were conducted on these golf balls. Determination of which material properties to be evaluated in this investigation was performed by Mr. Larry Cadorniga. In consulting with Mr. Cadorniga, I determined the manner in which these properties were to be tested. These material properties included hardness and specific gravity of the core, intermediate layer and cover, 100 kg distortion of the ball and core, thickness and diameter of various golf ball components and a rebound/drop test. Test protocols were developed for each specific test requested

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by Mr. Cadorniga. When developing these test protocols, I relied upon my background and personal experiences, as well as published testing standards by organizations such as The American Society of Testing Materials (ASTM) and Japanese Industrial Standards (JIS). Testing was conducted after a review of these protocols by Mr. Cadorniga. The test protocols developed and utilized in the evaluations of these golf balls are contained in Exhibits EX-4 to EX-12. The results of these evaluations are presented in the following section of this report.

13. The table below identifies the individual golf balls tested during this investigation. A "Golf Ball Model" designation was assigned to identify different versions of the same brand name golf ball manufactured by Acushnet. The model designation was necessary because Acushnet manufactures different revisions of golf balls under the same brand name. For example, as shown in the table below, Acushnet manufactured a total of four different versions of the Pro V1 golf ball. These four different versions are identifiable by the sidestamp markings on the side of the golf ball as well as the core color. In order to distinguish these different versions of the same brand name golf ball, "Golf Ball Model" designations were assigned to the different versions of the golf balls as listed in this table. For example, a P4 designation denoted a Pro V1 golf ball consisting of a green core and ◀Pro V1-392▶ sidestamp whereas a P3 designation denoted a Pro V1 golf ball consisting of a dark blue core and ◀●Pro V1 392●▶ sidestamp.

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Brand	Name	Sidestamp	Core Color	Golf Ball Model
Titleist	Pro V1	Pro V1 392*	Violet	P1
		◀Pro V1•392▶	Violet	P2
		◀•Pro V1 392•▶	Dark Blue	P3
		◀Pro V1-392▶	Green	P4
	Pro V1*	◀Pro V1* 392▶	Yellow/Blue	PS
	Pro V1x	◀•Pro V1x 332•▶	Orange/Blue	PX1
		◀Pro V1x-332▶	Dark Rd/Gray	PX2
	NXT	◀NXT▶	Dark Red	N1
		◀-NXT-▶	Red	N2
	NXT Tour	◀NXT•Tour▶	Royal Blue	NT1
		◀NXT Tour▶	Dark Green	NT2
		◀NXT-Tour▶	Black/Yellow	NT3
	DT So/Lo	DT So/Lo	Dark Orange	D1
		◀DT So/Lo▶	Aqua Blue	D2
Pinnacle	Exception	Pinnacle Exception	Light Green	E1
		Pinnacle	Light Blue	E2

* Sidestamp "Pro V1 392" in the table above includes both versions of the Pro V1 golf ball bearing the sidestamp "Pro V1 392", Pro V1 392 and Pro V1 392 (stretched).

V. RESULTS

A. Specific Gravity

14. The results of the specific gravity testing for Titleist Pro V1x (models PX2 and PX1), Pro V1 (models P4 and P3) and Pro V1 Star (model PS) golf balls are shown in Exhibit EX-13, Table I, Specific Gravity Results for Pro V1x, Pro V1 and Pro V1 Star. For each individual ball tested, the specific gravity of the core, intermediate layer and cover were determined. All testing was performed in accordance with the specific gravity test protocol contained in Exhibit EX-5. Table I reports the average, standard deviation, minimum and maximum value of the specific gravity for each component from twenty-four (24) balls from golf ball models PX2 and P4. Twelve (12) balls were tested from golf ball models PX1, P3 and PS.

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B. Core Rebound

15. The results of the Core Rebound testing for Titleist Pro V1x (model PX2), Pro V1 (model P4), NXT Tour (model NT3), NXT (model N2) and DT So/Lo (model D2) golf balls, sold in both the United States and Japan, are shown in Exhibit EX-14, Table II, Core Rebound Results for Pro V1x, Pro V1, NXT Tour, NXT and DT So/Lo. The rebound testing was performed in accordance with the rebound test protocol contained in Exhibit EX-6. The values reported in Table II contain the average, standard deviation, minimum and maximum values for the combined average values for each ball model. For this test a total of ten (10) cores were used for each ball model except the Pro V1 (P4) where twelve (12) cores were utilized. Each individual core was dropped three times and the results of these three drops were used to obtain the average rebound height for each individual ball. In five instances, only two drops were used to calculate the average rebound height.

16. In four of these instances, a difference of greater than 6.5 mm was observed between the lowest and highest rebound height value. In all four of these instances the low value was significantly different (lower) compared to the other two rebound heights and as such this low value was not used to calculate the average rebound height for that specific core. It is believed the core most likely grazed the 50 mm diameter ring gauge located at a height of 840 mm above the rebound striking surface during the tests which resulted in significantly lower rebound height values. As stated in the test protocol (Exhibit EX-6), the ball must successfully fall and rebound through this ring gauge to be a valid test.

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17. In the fifth instance, the test data from one drop of the core identified as P4.JPN.20 was not recorded correctly. An error occurred during the saving of the high speed video file from this specific drop.

C. Ball and Core Compression – Distortion Under 100 kg Load

18. The results of the compression testing, for determining the distortion under 100 kg load, for Titleist NXT Tour (models NT3 and NT2), NXT (models N2 and N1), DT So/Lo (models D2 and D1), and Pinnacle Exception (models E2 and E1) golf balls are shown in Exhibit EX-15, Table III Compression - Distortion Under 100 kg Load for NXT Tour, NXT, DT So/Lo and Pinnacle Exception. All compression was performed in accordance with the test protocol for ball and core distortion under a 100 kg load contained in Exhibit EX-7. Seventy-two (72) balls were tested from golf ball models NT3, D2 and N2. Forty-eight (48), fifty-two (52), twenty-three (23), twenty-one (21) and twenty (20) balls were tested from golf ball models E2, E1, NT2, N1 and D1, respectively. Each ball and core was tested one time. The data in Table III represents the average, standard deviation, minimum and maximum values for each model tested.

D. Cover and IML Thickness – Pro V1, Pro V1x and Pro V1 Star

19. The results for the cover and intermediate layer (IML) thickness testing for Pro V1x (models PX2 and PX1), Pro V1 (models P4, P3 and P2) and Pro V1 Star (model PS) golf balls are shown in Exhibit EX-16, Table IV, Cover and Intermediate Layer Thickness for Pro V1, Pro V1x and Pro V1 Star. As discussed in the test protocol (Exhibit EX-8), both the cover and IML thickness was measured at six random spots around the ball's

circumference. The average of these six values was then calculated for each individual ball. Seventy-two (72) balls were tested from golf ball models P4 and PX2. Thirty-five (35), five (5), twenty-four (24) and forty-three (43) balls were tested from golf ball models P3, P2, PS and PX1, respectively. Exhibit EX-26 contains seven bar charts, six of which represent the number of balls as a function of average cover thickness for each individual ball tested for golf ball models PX2, PX1, P4, P3, P2 and PS, respectively. The last chart is a compilation of all the Pro V series golf balls (models PX2, PX1, P4, P3, P2 and PS).

20. Exhibit EX-27 contains seven bar charts, six of which represents the number of balls as a function of average intermediate layer (IML) thickness for each individual ball tested for golf ball models PX2, PX1, P4, P3, P2 and PS, respectively. The last chart is a compilation of all the Pro V series golf balls (models PX2, PX1, P3, P2 and PS) except golf ball model P4. Model P4 was excluded from the combined data since Acushnet manufacturing guidelines dictate the P4 model is manufactured with a larger IML compared to the other Pro V series models (models PX2, PX1, P3, P2 and PS).

E. Cover Thickness – NXT Tour, NXT, DT So/Lo and Pinnacle Exception

21. The cover thickness results for NXT Tour (models NT3 and NT2), NXT (models N2 and N1), DT So/Lo (models D2 and D1), and Pinnacle Exception (models E2 and E1) golf balls are shown in Exhibit EX-17, Table V, Cover Thickness Results for NXT Tour, NXT, DT So/Lo and Pinnacle Exception. As stated in the test protocol (Exhibit EX-8), the cover thickness was measured at six random spots around the ball's circumference.

The average of these six values was then calculated for each individual ball. Seventy-two (72) balls were tested from golf ball models NT3, N2 and D2. Forty-seven (47), fifty-two (52), twenty-three (23), twenty-one (21), and twenty (20) balls were tested from golf ball models E2, E1, NT2, N1 and D1, respectively.

22. Exhibit EX-28 contains eight bar charts representing the number of balls as a function of average cover thickness for each individual ball tested for golf ball models NT3, NT2, N2, N1, D2, D1, E2 and E1, respectively.

F. Core Hardness

23. The core hardness results for Pro V1 (model P2), Pro V1 Star (model PS), NXT models (models N2 and N1), DT So/Lo (models D2 and D1) and Pinnacle Exception (models E2 and E1) golf balls are shown in Exhibit EX-18, Table VI, Core Hardness (JIS C) for Pro V1, Pro V1 Star, NXT, DT So/Lo and Pinnacle Exception. All core hardness testing was performed in accordance with the core hardness test protocol contained in Exhibit EX-9. For golf ball model PS, twenty-four (24) golf balls were tested and core hardness testing was only performed on the surface of the core.

24. Golf balls Pro V1 (model P2), NXT (models N2 and N1), DT So/Lo (models D2 and D1) and Pinnacle Exception (models E2 and E1) were all tested at the core surface and as well as at the core center. Sixty (60) balls were tested for golf ball models N2 and D2. Thirty-six (36), fifty-two (52), twenty-one (21), twenty (20) and five (5) balls were tested from golf models E2, E1, N1, D1 and P2, respectively.

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25. In Table VI, the average value reported for the core surface represents the combined average of all balls tested for each ball model tested. In accordance with the test protocol (Exhibit EX-9), hardness measurements were performed at five different locations around the core's circumference. An average core surface hardness value was then calculated for each individual ball. The combined average, standard deviation, minimum and maximum values reported for each golf ball model in Table VI were then determined from the individual ball average hardness values.

26. Two significantly different core colors were observed between balls from golf ball models E2 and D2. Group FF from golf ball model D2 had a dark blue core whereas the other D2 model balls had aqua blue cores. These darker blue cores (Model D2, Group FF) had a lower surface hardness compared to the other model D2 balls tested. The average surface hardness from nine (9) model D2, group FF balls, was 75.2 JIS C compared to the overall D2 model average of 82.1 JIS C.

27. Cores from group GG, golf ball model E2, also contained cores whose color differed from the other cores from model E2. These cores (model E2, group GG) were very light blue colored whereas the other cores from group E2 had a darker blue core. The surface hardness on golf ball model E2, group GG were lower compared to the other balls tested from model E2. The average surface hardness from nine (9) model E2, group GG balls, was 73.9 JIS C compared to the overall E2 model average of 79.1 JIS C.

28. In Table VI, the average value reported for the core center hardness represents the combined average of all individual balls tested for each ball model tested. In accordance

with the test protocol (Exhibit EX-9), five hardness measurements were performed at core's center. An average core center value was then calculated for each individual ball. The combined average, standard deviation, minimum and maximum values reported for each golf ball model in Table VI were then determined from these individual ball average hardness values.

29. In addition to the core surface and core center hardness testing, twenty-four balls (24) from golf balls NXT (model N2) and Pinnacle Exception (models E2 and E1) and twenty-two (22) from DT So/Lo (model D2) were also tested for hardness using specimens prepared from the core's outermost 5 mm. This testing was performed in accordance with the "Hardness at 5 mm Within the Surface of the Core" section of the Core Hardness and Diameter Measurement Protocol contained Exhibit EX-9. In accordance with the protocol, these test samples extended radially from the core's surface to a depth of 5 mm below the core surface. On each ball, five hardness measurements were performed at the center of the plane representing a depth of 5 mm radially below the core surface. This hardness measurement represents the core hardness within 5 mm of the core surface.

30. In Table VI, the average value reported for the core hardness within 5 mm of the core surface represents the combined average of all balls tested for each golf ball model tested. The combined average, standard deviation, minimum and maximum values reported for each golf ball model in Table VI were determined from the individual ball average hardness values.

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31. The difference between the hardness at the core surface and hardness within 5 mm of the core surface was computed using the average hardness values at these two locations for each individual ball. Exhibit EX-29 contains four bar charts showing the number of balls as a function of the hardness difference between the core surface and material within 5 mm of the core surface for each individual ball tested for golf ball models N2, D2, E2 and E1. Table VI contains the combined average of this hardness difference for each golf ball model tested.

G. Core Hardness Gradient – Pro V1x (PX2 and PX1)

32. The core hardness gradient test results for Pro V1x (models PX2 and PX1) golf balls are shown in Exhibit EX-19, Table VII, Pro V1x Core Hardness Gradient (JIS C). Sixty (60) and forty-three (43) golf balls were tested from models PX2 and PX1, respectively. The surface and core center hardness testing was performed as described in paragraphs 25 and 28 above.

33. In addition to the surface and core center, hardness testing was also performed at a distance of 3.5 mm, 7 mm and 13.4 mm below the core's surface. In accordance with the test protocol (Exhibit EX-9), on each individual ball, five hardness measurements were performed at each of these locations. An average value was then calculated for each of the three locations for every individual ball. The combined average, standard deviation, minimum and maximum values reported for each golf ball model in Table VII were then determined from these individual ball average hardness values.

34. Exhibit EX-30 contains sixty-one charts, sixty of which depict the core hardness gradient for each individual model PX2 ball tested. The final chart depicts the combined average core hardness gradient for golf ball model PX2. There are five points plotted on each of the charts representing the five hardness test locations described above.

35. Exhibit EX-31 contains forty-four charts, forty-three of which depict the core hardness gradient for each individual model PX1 ball tested. The final chart depicts the combined average core hardness gradient for golf ball model PX1. There are 5 points plotted on each of the charts representing the five hardness test locations described above.

H. Core Hardness Gradient – Pro V1 (P4 and P3)

36. The core hardness gradient test results for Pro V1 (models P4 and P3) golf balls are shown in Exhibit EX-20, Table VIII, Pro V1 Core Hardness Gradient (JIS C). Sixty (60) and thirty-five (35) golf balls were tested from models P4 and P3, respectively. The surface and core center hardness testing was performed as described in paragraph 25 and 28 above.

37. In addition to the surface and core center, hardness testing was all performed at a distance of 6.5 mm and 13 mm below the core's surface for model P4. Due to the P3 model's larger nominal core diameter, these dimensions were increased slightly to 6.6 mm and 13.1 mm for the P3 model. In accordance with the test protocol (Exhibit EX-9), on each individual ball, five hardness measurements were performed at each of these locations. An average value was then calculated for each of these locations for every individual ball. The combined average, standard deviation, minimum and maximum values reported

for each golf ball model in Table VIII were then determined from these individual ball average hardness values.

38. Exhibit EX-32 contains sixty-one charts, sixty of which depict the core hardness gradient for each individual P4 ball tested. The final chart depicts the combined average core hardness gradient for golf ball P4. There are four (4) points plotted on each of the charts representing the four hardness test locations described in paragraphs 36 and 37 above.

39. Exhibit EX-33 contains thirty-six charts, thirty-five of which depict the core hardness gradient for each individual P3 ball tested. The final chart depicts the combined average core hardness gradient for golf ball model P3. There are of four (4) points plotted on each of the charts representing the four (4) hardness test locations described in paragraphs 33 and 34 above.

I. IML Hardness – Packer Engineering Prepared Plaques

40. The intermediate layer (IML) hardness test results, performed on Packer Engineering prepared plaques in accordance with Exhibit 11, for Pro V1x (models PX2 and PX1), Pro V1 (models P4 and P3), and Pro V1 Star (model PS) golf balls are shown in Exhibit Ex-21, Table IX, Intermediate Layer Hardness Results for Pro V1x, Pro V1 and Pro V1 Star (Packer Engineering Prepared Plaques). Seven (7), four (4), eight (8), three (3), and four (4) hardness plaques were prepared and tested in accordance with the Test Protocol for Intermediate Layer Hardness contained in Exhibit EX-10 from golf ball models PX2, PX1, P4, P3 and PS, respectively. IML test plaque PX1.TT was not utilized due to an

uneven test surface. As such, only three test plaques were used in the values calculated for model PX1.

J. **Cover Hardness – Acushnet Prepared Plaques**

41. The cover hardness test results, performed on Acushnet prepared plaques, for NXT Tour, NXT and DT So/Lo golf balls are shown in Exhibit EX-22, Table X, Cover Hardness (Acushnet Prepared Plaques) for NXT Tour, NXT and DT So/Lo. The thirty-six (36) test plaques were identified with Bates numbers AB0087883 – AB0087918. All thirty-six (36) plaques were also identified with a hand written date of 7/23/2004 on the top side of each test plaque. Testing on these plaques was performed in accordance with the Test Protocol for Cover Hardness – Acushnet Prepared Plaques contained in Exhibit EX-11. The values reported in Table X represent the combined average, standard deviation, minimum, and maximum values determined from the individual plaque average hardness values.

K. **Cover Hardness – Packer Engineering Prepared Plaques**

42. The cover hardness test results, performed on Packer Engineering prepared plaques for NXT Tour (models NT3 and NT2), NXT (models N2 and N1), DT So/Lo (models D2 and D1) and Pinnacle Exception (models E2 and E1) golf balls are shown in Exhibit EX-23, Table XI, Cover Hardness (Packer Engineering Prepared Plaques) for NXT Tour, NXT, DT So/Lo and Pinnacle Exception. Packer Engineering prepared and tested three plaques from each ball model in accordance with the Test Protocol for Cover Hardness – Packer Engineering Prepared Plaques contained Exhibit EX-12. The values reported in

Table XI represent the combined average, standard deviation, minimum, and maximum values determined from the individual plaque average hardness values.

L. Ball Diameter

43. The results of the ball diameter measurements for Pro V1x (models PX2 and PX1), Pro V1 (models P4, P3 and P2), Pro V1 Star (model PS), NXT Tour (models NT3 and NT2), NXT (models N2 and N1), DT So/Lo (models D2 and D1) and Pinnacle Exception (models E2 and E1) golf balls are shown in Exhibit EX-24, Table XII, Ball Diameter Results.

M. Core Diameter

44. The results of the core diameter measurements for Pro V1x (models PX2 and PX1), Pro V1 (models P4, P3 and P2), Pro V1 Star (model PS), NXT Tour (models NT3 and NT2), NXT (models N2 and N1), DT So/Lo (models D2 and D1) and Pinnacle Exception (models E2 and E1) golf balls are shown in Exhibit EX-25, Table XIII – Core Diameter Results.

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VI. CONCLUSION

45. I hereby declare under penalty of perjury that all of the foregoing statements are based on my personal knowledge and are true and correct to the best of my knowledge and belief. If called upon as a witness, I could and would testify competently to the matters stated in this report.

E. M. Caulfield

Dated: January 15, 2007

Edward M. Caulfield, Ph.D., P.E.
President and Chief Technical Officer

EX-1

Edward M. Caulfield, Ph.D., P.E.

President and Chief Technical Officer

EDUCATION - DEGREES

Ph.D. Theoretical and Applied Mechanics, University of Illinois at Urbana-Champaign, 1979
M. S. Theoretical and Applied Mechanics, University of Illinois at Urbana-Champaign, 1974
B.S. Mechanical Engineering, University of Illinois at Urbana-Champaign, 1972

HONORS

1976 - Award for excellence in undergraduate teaching, University of Illinois at Urbana-Champaign (campus-wide)

1975 - J. 0. Smith award for excellence in undergraduate teaching, Department of Theoretical and Applied Mechanics, University of Illinois at Urbana-Champaign.

2000 - First TAM Distinguished Alumni Award for technical accomplishments in Theoretical and Applied Mechanics, and serving in a professional and technical capacity that reflects honor on the department and University, Department of Theoretical and Applied Mechanics, University of Illinois at Urbana-Champaign.

SOCIETIES

Sigma Xi, ASME, ASTM, ISPE, NSPE, SAE, AAAM, HFES

REGISTRATION

Registered Professional Engineer in State of Illinois
Registered Professional Engineer in State of Florida

ACADEMIC AND TEACHING EXPERIENCE

1978-1979	University of Illinois at Urbana-Champaign, Department of Mechanical Engineering - Assistant Professor-Machine Design
1972-1978	University of Illinois at Urbana-Champaign, Department of Theoretical and Applied Mechanics - Graduate Research and Teaching Assistant

INDUSTRIAL EXPERIENCE

1998 - Present	Packer Engineering, Inc. Naperville, IL President & Chief Technical Officer

1995 - 1998	Packer Engineering, Inc. Naperville, IL President
1990 -1995	Packer Engineering, Inc. Naperville, IL Chief Operating Officer Executive Vice President
1986 - 1990	Packer Engineering Associates, Inc. Naperville, IL Vice President
1979 - 1985	Packer Engineering Associates, Inc. Naperville, IL Director of Mechanical Engineering
1975 - 1978	Structural Dynamics Research Corporation (SDRC) Cincinnati, OH Consulting and seminar presentations Fatigue, Fracture Mechanics, Failure Analysis & Prevention
1975 - 1978	Consultant to members of Ground Vehicle Industry Fatigue, Fracture Mechanics, Failure Analysis, Dynamics of Machinery
1969 - 1972	Teletype Corporation Skokie, IL Cooperative Education

NON-PUBLISHED CORPORATE REPORTS AND INVESTIGATIVE STUDIES

Design
Machine design employing the multi-disciplined areas of ergonomics, materials and dynamic stress analysis to obtain minimum risk configurations.

Accident Reconstruction
Analyzing numerous industrial, traffic, aircraft and structural accidents employing the principles of advanced dynamics and modern investigative engineering techniques.

Industrial Machine Design
Evaluation of restraint systems and operator stations for industrial equipment from the biomechanical and ergonomic standpoints employing anthropometric test devices (ATD).

Intellectual Property
Evaluation of numerous components, apparatus or machines for infringement or non-infringement of various patents.

Turbine/Generator Rotor Reliability Analysis
Probabilistic fracture mechanics, computerized finite element methods, empirical temperature data and practical experience incorporated to provide a criterion from which major utility companies may engage in an appropriate run-retire decision making process.

Fatigue Analysis
In-field strain histograms, material properties and simulated tests incorporated to determine the fatigue life of structural components. Suggestive alternative designs were presented to provide longer fatigue life in typical fatigue service applications.

Fracture Analysis
Determine cause of structural component fracture in the following disciplines: fatigue, brittle fracture, structural overload, corrosion, creep, etc.

Structural Analysis
Evaluate through analytical and experimental techniques the adequacy of various mechanical configurations designed for static load carrying capacity.

Material Properties
Evaluation of metallic, polymer, and ceramic material parameters such as modulus, hardness, fracture toughness, crack growth rate, strain-life curves for fatigue, creep properties, true/engineering stress strain curves for material selection purposes in commercial machine design and sporting goods applications.

PUBLICATIONS

"TURBINE ROTOR RELIABILITY: A PROBABILITY MODEL FOR BRITTLE FRACTURE"
Authors: E. M. Caulfield, M.T. Cronin, W. B. Fairley, N.E. Rallis
Published by Society for Risk Analysis, Proceedings 1983, Annual Meeting 1983.

"AN APPROACH TO RELIABILITY ANALYSIS OF CRACKED CONTINUOUS DIGESTERS"
Authors: E. M. Caulfield, C. R. Morin, J. E. Slater
Published by NACE (National Association of Corrosion Engineers), Houston, TX, March 1982.

"ROTOR RELIABILITY ASSESSMENT IN THE ELECTRIC POWER INDUSTRY"
Authors: E. M. Caulfield, M. T. Cronin
Published by Edison Electric Institute (The Association of Electric Companies) at 9th Annual Engineering Conference on Reliability, Hershey, PA, June 1982.

"AN INVESTIGATION OF STRESS-DEPENDENT; TEMPERATURE-DEPENDENT; AND TIME-DEPENDENT STRAINS IN RANDOMLY ORIENTED FIBER REINFORCED COMPOSITES"

Author: E. M. Caulfield

Published by ASTM (American Society for Testing and Materials) Philadelphia, PA, 1982, Chapter - Short Fiber Reinforced Composite Materials, ASTM STP 772.

"AN INVESTIGATION OF STRESS, TEMPERATURE, AND TIME DEPENDENT STRAINS IN A RANDOMLY ORIENTED FIBER REINFORCED COMPOSITE WITH SPECIAL EMPHASIS GIVEN TO THERMAL STRESS SITUATION"

Author: E. M. Caulfield

Published by University of IL, Urbana, IL, T&AM Report No. 432, December 1978.

"FUNDAMENTALS OF MODERN FATIGUE ANALYSIS"

Authors: D. F. Socie, M.R. Mitchell, E.M. Caulfield

Published by University of IL, Urbana, IL, FCP Report No. 26, April 1977, Revised December 1979.

"FRACTURE MECHANICS PARAMETERS OF A-27 CAST STEEL"

Author: E. M. Caulfield

Published by University of IL, Urbana, IL, FCP Report No. 28, December 1977.

SEMINARS AND PRESENTATIONS

"Productivity in Modern Heat Treating Practices," Northern Illinois Heat Treaters Association, Rockford, IL, April 1980.

"Modern Fatigue Analysis," ASM Chicago-Western Chapter, April 1980.

"Technical Aspects of Modern Failure Analysis," Westec Conference, Los Angeles, CA, March 1980.

"Temperature, Stress and Time Dependent Strains in Fiber Reinforced Polymers," ASTM Conference, Minneapolis, MN, March 1980.

"Modern Fatigue Analysis," National Water Lift, Kalamazoo, MI, March 1979.

"Thermal Stress Computations for Materials with Highly Varying Modulii over Temperature," Stellite Corporation, Division of Cabot. Kokomo, IN, December 1978.

"Fracture Toughness Properties of A-27 Cast Stee,l" University of Illinois, November 1978.

"Fundamentals of Modern Fatigue Analysis", Structural Dynamics Research Corporation, Cincinnati, OH, January 1977; Cincinnati, OH, June 1977; Chicago, IL, December 1977; Cincinnati, OH, June 1978.

"Fundamentals of Modern Fatigue Analysis," University of Illinois, January 1977; June 1977; January 1978; June 1978.

"Modern Fatigue Analysis," General Motors Proving Ground, Milford, MI, August 1977.

"Refresher Course for 'Engineer in Training' in State of Illinois," University of Illinois, Spring, Fall, 1973, 1974, 1975, 1977. Sponsored by A.S. C. E. Student Chapter.

"Strain Components in Glass Fiber Reinforced Composites," University of Illinois, September 1976.

"Theory and Applications of Fracture Mechanics," Marion Power Shovel Company, Marion, OH, June 1975.

"Fracture Mechanics Parameters of A-27 Cast Steel," Clark Equipment Company, Niles, MI, June 1975.

"Introduction to Fracture Mechanics," Rexnord Corporation, Milwaukee, WI, June 1975.

Edward M. Caulfield, Ph.D., P.E
Testimony Record

December 10, 2002, Atlanta, GA
Haun (Michael David, et al v Ford Motor Company)
Case No.: 2:01-2238-18
Law Firm: Nelson Mullins Riley & Scarborough, Columbia, SC
Deposition Testimony

December 18, 2002, Wheaton, IL
McSweegan (Kevin) v. The Raymond Corporation
Case No.: CV-99-0593206-S
Law Firm: Day, Berry & Howard, Hartford, CT
Deposition Testimony

January 10, 2003, Chicago, IL
Eaton Corporation v. Parker Hannifin Corporation
Case No.: C.A. No. 00-751-SLR
Law Firm: Ross & Hardies, Chicago, IL
Deposition Testimony

January 15, 2003, Naperville, IL (telephonic)
Royas (Albert E.) V. Mercedes Benz, USA, Inc.; Daimler Chrysler AG; Behr Climate Control; and Does 1-50, Inclusive
Case No.: BC223738
Law Firm: Carroll Burdick & McDonough
Deposition Testimony (Vol. II)

January 28-29, 2003, Los Angeles, CA
Royas (Albert E.) V. Mercedes Benz, USA, Inc.; Daimler Chrysler AG; Behr Climate Control; and Does 1-50, Inclusive
Case No.: BC223738
Law Firm: Carroll Burdick & McDonough
Trial Testimony

February 4-5, 2003, Wilmington, Delaware
Eaton Corporation v. Parker Hannifin Corporation
Case No.: C.A. No. 00-751-SLR
Law Firm: Ross & Hardies, Chicago, IL
Trial Testimony

February 19, 2003, Lisle, IL
Cunningham (George) v Case Corporation et al.
Case No.: CA 94-RCCV-222
Law Firm: Nelson Mullins Riley & Scarborough, Atlanta, GA
Deposition Testimony

February 28, 2003, Chicago, IL
Romero (Jesus and Fabiana) vs. Walt Disney World Hospitality & Recreation Corporation
Case No.: CI198-7768
Law Firm: Cabaniss, Smith, Toole & Wiggins, Maitland, FL
Deposition Testimony

Edward M. Caulfield, Ph.D., P.E
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March 3, 2003, Naperville, IL
Redding (Kaye) and Drew and Jacob v Ford Motor Company, TRW Vehicle Safey System, Inc., Lindeberger Chevrolet, Inc. and Action Ford-Mercury, Inc.
Case No.: 00CPI60690
Law Firm: Nelson Mullins Riley & Scarborough, Columbia, SC
Deposition Testimony

March 11, 2003, Rosemont, IL
Hirn (Ronald Allan) et al v. Land Rover U.K. Ltd., Land Rover N.A. Inc., Continental General Tire, Inc., The Tire Corral Inc., Gunn Infinity d/b/a Gunn Range Rover
Case No.: 28,564-A
Law Firm: Wheeler Trigg & Kennedy P.C., Denver, CO
Deposition Testimony

May 30, 2003, Wheaton, IL
Collins (Stephanie) vs. Ford Motor Company; West Colton Cars, Inc. D/B/A Redlands Ford; Michael Loren Butler; and Does 1 through 50, inclusive
Case No.: RIC361201
Law Firm: Snell and Wilmer, Irvine, CA
Deposition Testimony

June 18, 2003, Burr Ridge, IL
Hopper (Mary Jane and Harrison) v. David Leon Baldwin, Nissan North America, Inc. and Nissan Motor Co., Ltd.,
Case No. 99-6596-CI-21
Law Firm: Rumberger, Kirk & Caldwell, P.A., Orlando, FL
Deposition Testimony

July 23, 2003, Wheaton, IL
Anderson (Craig A. and Christina L. Palomo-Anderson), et al vs. ABC Insurance Company, Raymond Corporation, DEF Insurance Company, Stoffel Equipment Company, Inc.
Case No. 02-CV-3113
Law Firm: Quarles & Brady, LLP, Milwaukee, WI
Deposition Testimony

July 24-25, 2003, Naperville, IL
Vulcan Litigation April 2001 Incidents
Case No. 69,388-A
Law Firm: Quarles & Brady, Milwaukee, WI
Deposition Testimony

August 7, 2003, Chicago, IL
Kinzenbaw (Jon) et al. vs. Case LLC, et al.
Case No. C01-133MJM
Law Firm: McGuire Woods Ross & Hardies, Chicago, IL
Deposition Testimony

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September 3, 2003, Wheaton, IL
Donald (Christopher S.), Jimmy Donald and Sherry Donald,
as Legal Guardians for Christopher S. Donald, and Matthew Lake
Case No. Civil Action No. 1:01CV408-JAD
Law Firm: Watkins & Eager PLLC, Jackson, MS
Deposition Testimony

September 5, 2003, Chicago, IL
Gibson (Artumus) Jr. as Surviving Spouse of
Anne Marie Gibson, Deceased, and Artumus G. Gibson, Jr., as
Administrator of the Estate of Anne Marie Gibson, Deceased v.
Ford Motor Company, Draw-Tite, Inc., and William M. Burns, III
Case No. Civil Action No. ST-00-CV-0111
Law Firm: McGuire Woods Ross & Hardies, Richmond, VA
Deposition Testimony

September 8, 2003, Wheaton, IL
Winn Incorporated and
Ben Huang v. Eaton Corporation
Case No. CV-03-1568 SJO
Law Firm: Sughrue Mion Zinn et al, Washington DC
Deposition Testimony

September 16, 2003, Naperville, IL
Canfield (Jacob) and Elizabeth Canfield v.
Ford Motor Company
Case No. 02CV211111, Division 16
Law Firm: Shook, Hardy & Bacon LLP, Kansas City, MO
Deposition Testimony

September 23, 2003, Chicago, IL
Chevez, Martha et al v. Ford Motor Company,
Jojet Viray Pilao, Sotero Pilao, Fermin Rovira; and
Does 1 to 200
Case No. EC032707
Law Firm: Bowman and Brooke, Minneapolis, MN
Deposition Testimony

September 26, 2003, Wheaton, IL
Adams (Pamela) v. Key Ford, Inc. and
Ford Motor Company
Case No. 98-1000-CA-01 (Div. B)
Law Firm: Cabaniss, Smith, Toole & Wiggins, Maitland, FL
Deposition Testimony

October 20, 2003, Cedar Rapids, IA
Kinzenbaw (Jon) et al. vs. Case LLC, et al.
Case No. C01-133MJM
Law Firm: McGuire Woods Ross & Hardies, Chicago, IL
Hearing Testimony

Edward M. Caulfield, Ph.D., P.E
Testimony Record

October 21, 2003. Kansas City, MO
Canfield (Jacob) and Elizabeth Canfield v.
Ford Motor Company
Case No. 02CV211111, Division 16
Law Firm: Shook, Hardy & Bacon LLP, Kansas City, MO
Trial Testimony

October 29, 2003, Aurora, IL
Hopper (Mary Jane and Harrison) v. David Leon Baldwin,
Nissan North America, Inc. and Nissan Motor Co., Ltd.,
Case No. 99-6596-CI-21
Law Firm: Rumberger, Kirk & Caldwell, P.A., Orlando, FL
Deposition Testimony (Supplemental)

October 30, 2003, Chicago, IL
Mathes (John) father of Jacob Mathes and son of John Mathes
and Shirley Mathes v. Sher Express LLC, Sentry Select Insurance Company
(Formerly known as John Deere Insurance Company), Ford Motor Company,
a Delaware Corporation, Festus Ford, Inc., a Delaware Corporation
and PlayMor Trailers, Inc.
Case No. 02 CV 204007
Law Firm: Shook Hardy and Bacon, Kansas City, MO
Deposition Testimony

November 12, 2003, Clearwater, FL
Hopper (Mary Jane and Harrison) v. David Leon Baldwin,
Nissan North America, Inc. and Nissan Motor Co., Ltd.,
Case No. 99-6596-CI-21
Law Firm: Rumberger, Kirk & Caldwell, P.A., Orlando, FL
Hearing

November 19, 2003, Chicago, IL
Pollesche, Leslie and Daniel on behalf of Danielle
Pollesche, a minor, and as surviving parent of
Cassandra Pollesche, deceased; Wesley T. Nixon;
Nena Clark on behalf of Cherise Clark, a minor v.
Ford Motor Company, Bell Ford, Inc., Xavier Ramirez,
Jane Doe Ramirez, and John Does I-X
Case No. CV2000-011238
Law Firm: Snell and Wilmer, Phoenix, AZ
Deposition Testimony

November 24, 2003, Wheaton, IL
Gonzalez (Alfonso Jr.), Valdez (Noemi), Chavarria (Noemi),]
Valdez (Rosa), Tijerina (Brenda), Tinajero (Elizabeth)
et al v. Ford Motor Company, Recio Auto Sales,
And the estate of Richard Alaniz, Jr.
Case No. DC-02-3332
Law Firm: McGuire Woods, Richmond, VA
Deposition Testimony

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Testimony Record

January 13, 2004, Wheaton, IL
McCoy (Robert Edward) vs. American Honda Motor Co., Inc.,
Honda Motor Company, LTD and Charles E. Jones
Civil Action No.: 2001-CP-23-7483
Law Firm: Nelson Mullins Riley & Scarborough LLP
Deposition Testimony

January 28, 2004, Greenville, SC
McCoy (Robert Edward) vs. American Honda Motor Co., Inc.,
Honda Motor Company, LTD and Charles E. Jones
Civil Action No.: 2001-CP-23-7483
Law Firm: Nelson Mullins Riley & Scarborough LLP
Trial Testimony

February 13, 2004, Los Angeles, CA
Chevez, Martha et al v. Ford Motor Company,
Jojet Viray Pilao, Sotero Pilao, Fermin Rovira; and
Does 1 to 200
Case No. EC032707
Law Firm: Bowman and Brooke, Minneapolis, MN
Supplemental Deposition Testimony

February 17-18, 2004, Los Angeles, CA
Chevez, Martha et al v. Ford Motor Company,
Jojet Viray Pilao, Sotero Pilao, Fermin Rovira; and
Does 1 to 200
Case No. EC032707
Law Firm: Bowman and Brooke, Minneapolis, MN
Trial Testimony

February 24, 2004, Los Angeles, CA
Chevez, Martha et al v. Ford Motor Company,
Jojet Viray Pilao, Sotero Pilao, Fermin Rovira; and
Does 1 to 200
Case No. EC032707
Law Firm: Bowman and Brooke, Minneapolis, MN
Supplemental Deposition Testimony

February 25, 2004, Los Angeles, CA
Chevez, Martha et al v. Ford Motor Company,
Jojet Viray Pilao, Sotero Pilao, Fermin Rovira; and
Does 1 to 200
Case No. EC032707
Law Firm: Bowman and Brooke, Minneapolis, MN
Trial Testimony

March 1, 2004, Independence, MO
Mathes (John) father of Jacob Mathes and son of John Mathes
and Shirley Mathes v. Sher Express LLC, Sentry Select Insurance Company
(Formerly known as John Deere Insurance Company), Ford Motor Company,
a Delaware Corporation, Festus Ford, Inc., a Delaware Corporation
and PlayMor Trailers, Inc.
Case No. 02 CV 204007
Law Firm: Shook Hardy and Bacon, Kansas City, MO
Trial Testimony

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April 12&14, 2004, Wheaton, IL
Jason and Suzie Schechterle, et al v. Ford Motor Company;
Lou Grubb Ford LLC; Xecore Corporation; et al.
Case No. CV2003-003427
Law Firm: Dykema Gossett, Bloomfield Hills, MI
Deposition Testimony

June 3, 2004, San Francisco, CA
Jarvis (Maria) individually and as personal representative
of the Estate of Dennis B. Jarvis; the Estate of Dennis B. Jarvis;
Carrie Ann Faraone; and James Pirnik, v. Audi AG et. al.,
Volkswagon of America; Volkswagenwek; Audi of America;
Marc James Naify d/b/a J&L Auto Repair; and Does 1 through 50
Case No. CIV428481
Law Firm: Carroll Burdick & McDonough, LLP, San Francisco, CA
Deposition Testimony

June 15, 2004, Wheaton, IL
Smith, Yvonne H. et al. v. Helena J. Cangieter et al.
Case No. 00-4045-CV-C-66BA
Law Firm: Polsinelli, Shalton, Welte, Suelthaus PC
Deposition Testimony

June 21, 2004, Oakbrook Terrace, IL
Strickland (Zachary) v Ford Motor Company
Case No. 4:00-1391-25
Law Firm: McGuire Woods, Richmond, VA
Deposition Testimony

July 9, 2004, Bloomingdale, IL
Phillips (Sammie) v The Raymond Corporation
Case No. 99 C 2152
Law Firm: Swanson Martin & Bell, Chicago, IL
Deposition Testimony

July 12, 2004, Lisle, IL
St. Clair County, et al. v. Ford Motor Company, et al.
Case No. 03-L-115
Law Firm: Dykema Gossett, PLLC, Bloomfield Hills, MI
Deposition Testimony

July 16, 2004, Wheaton, IL
Wheeler (Randy Eugene) v. Ben Satcher Motors, Inc.,
and Ford Motor Company, Inc.
Case No. 01-CP-32-0656
Law Firm: Cabaniss Smith Toole & Wiggins PL, Maitland, FL
Deposition Testimony

August 10-11, 2004, Chicago, IL
Automated Mechanical Transmission Systems
for Medium-Duty and Heavy-Duty Trucks of
Components Thereof
Investigation No. 337-TA-503 (U.S. Int'l Trade Commission, Wash. DC)

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Law Firm: Sughrue Mion PLLC, Washington DC
Deposition Testimony
August 25, 2004, Chicago, IL
Kinzenbaw (Jon) et al. vs. Case LLC, et al.
Case No. C01-133MJM
Law Firm: McGuire Woods, Chicago, IL
Deposition Testimony

September 7-9, 2004, Washington D.C.
Automated Mechanical Transmission Systems
for Medium-Duty and Heavy-Duty Trucks of
Components Thereof
Investigation No. 337-TA-503 (U.S. Int'l Trade Commission, Wash. DC)
Law Firm: Sughrue Mion PLLC, Washington DC
Trial Testimony

September 15, 2004, Washington D.C.
Automated Mechanical Transmission Systems
for Medium-Duty and Heavy-Duty Trucks of
Components Thereof
Investigation No. 337-TA-503 (U.S. Int'l Trade Commission, Wash. DC)
Law Firm: Sughrue Mion PLLC, Washington DC
Trial Testimony (Rebuttal)

September 24, 2004, Rosemont, IL
Hardy (Richard M.) V. U.S. Foodservice, Inc., formerly
PYA/Monarch, Inc., a Corporation, The Raymond Corporation,
a corporation, et al.
Case No. CV-02-1239-R
Law Firm: Lightfoot Franklin & White LLC, Birmingham, AL
Deposition Testimony

September 29, 2004, Naperville, IL
Sears, Roebuck and Co., a New York Corporation,
and Alfredo E. Jijon, Third-Party Plaintiffs, v.
Charwil Associates Limited Partnership; Acceptance
Insurance Company Travelers Casualty and Surety
Company, f/k/a Aetna Casualty and Surety Company and
Rosa L. Kresin
Deposition Testimony

October 12, 2004, Redwood City, CA
Jarvis (Maria) individually and as personal representative
of the Estate of Dennis B. Jarvis; the Estate of Dennis B. Jarvis;
Carrie Ann Faraone; and James Pirnik, v. Audi AG et. al.,
Volkswagon of America; Volkswagenwek; Audi of America;
Marc James Naify d/b/a J&L Auto Repair; and Does 1 through 50
Case No. CIV428481
Law Firm: Carroll Burdick & McDonough, LLP, San Francisco, CA
Trial Testimony

October 14, 2004, Bellville, IL
St. Clair County, et al. v. Ford Motor Company, et al.
Case No. 03-L-115
Law Firm: Dykema Gossett, PLLC, Bloomfield Hills, MI

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Trial Testimony

October 15, 2004, St. Louis, MO
Galvan (Cruz Macias), individually and on behalf of the estate of
Sergio Alberto Macias, deceased and Victorino Quiroga as
next friend of Diego A. Quiroga, a minor v. David Garcia,
Mercedes Garcia, Rodriguez Ford-Mercury, Inc.,
Ford Motor Company, and TRW Vehicle Safety Systems, Inc.
Case No. 2002-04-1485-B
Law Firm: Snell & Wilmer L.L.P., Tucson, AZ
Deposition Testimony

November 22-23, 2004, Cedar Rapids, IA
Kinzenbaw (Jon) et al. vs. Case LLC, et al.
Case No. C01-133MJM
Law Firm: McGuire Woods, Chicago, IL
Trial Testimony

December 7, 2004, Wheaton, IL
Deno (Joshua) v Ford Motor Company
Case No. 96-CI-00293
Law Firm: Baker Donelson, Nashville, TN
Deposition Testimony

December 28, 2004, Naperville, IL
Coleman (Sandra) as Personal Representative of
The Wrongful Death Beneficiaries of Randy Coleman,
Deceased vs. Ford Motor Company, Premier Ford
Lincoln-Mercury, Inc.; Mary Ruth Shelton, as
Administratrix of the Estate of Janice Hudson, Deceased
Civil Action No. 2002-0209-CV-1
Law Firm: McGuire Woods, Richmond, VA
Deposition Testimony

January 4, 2005, Chicago, IL
Jablonksi (Dora Mae) and John L. Jablonski, Jr. As
Special Administrator and Personal Representative
Of the Estate of John L. Jablonski, Sr. vs. Ford
Motor Company and Natalie S. Ingram
Case No.: 03-L-2027
Law Firm: Dykema Gossett, Bloomfield Hills, MI
Deposition Testimony

January 7, 2005, Wheaton, IL
Lee (Jenny and Changshi) et al. v Nissan Motor Company et al.
Case No. 012-08476
Law Firm: Sandberg, Phoenix & von Gontard, St. Louis, MO
Deposition Testimony

January 18, 2005, Philadelphia, PA
Ortiz (Daniel) v Yale Materials Handling Corporation,
Hyster-Yale Materials Handling, Inc., and
John Doe Manufacturer
Case No. 03-CV-3657

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Law Firm: Lavin O'Neill Ricci Cedrone & DiSipio, Philadelphia, PA
Deposition Testimony

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January 20, 2005, Knoxville, TN
Teets (Linda B.) et al vs. Millennium Trucking, Inc., et al.,
Defendant and Third-Party Plaintiff vs. Ford Motor Company,
Third Party Defendant
Case No. 3:01-CV-415
Trial Testimony

February 8, 2005, Wheaton, IL
Jablonksi (Dora Mae) and John L. Jablonski, Jr. As
Special Administrator and Personal Representative
Of the Estate of John L. Jablonski, Sr. vs. Ford
Motor Company and Natalie S. Ingram
Case No.: 03-L-2027
Law Firm: Dykema Gossett, Bloomfield Hills, MI
Deposition Testimony (Vol. II)

February 25, 2005, Wheaton, IL
Freedle (Steven L.) vs. Ford Motor Company,
Cerbat Hills Ford Lincoln Mercury, LLC d/b/a
Colorado River Ford, et al.
Deposition Testimony

March 3, 2005, Beaver Dam, KY
Deno (Joshua) v Ford Motor Company
Case No. 96-CI-00293
Law Firm: Baker Donelson, Nashville, TN
Trial Testimony

March 18, 2005, Florence, SC
Strickland (Zachary) v Ford Motor Company
Case No. 4:00-1391-25
Law Firm: McGuire Woods, Richmond, VA
Trial Testimony

March 21, 2005, Florence, SC
Strickland (Zachary) v Ford Motor Company
Case No. 4:00-1391-25
Law Firm: McGuire Woods, Richmond, VA
Trial Testimony (continued)

March 25, 2005, Chicago, IL
Newton (Shonnie) et al. v. Ford Motor Company et al.
Nolte (Michael and Barbie) v. Ford Motor Company and
Trade Winds Distributing, Inc.
Case No. 03CV215677
Law Firm: Dykema Gossett, Bloomfield Hills, MI
Deposition Testimony

April 18, 2005, Edwardsville, MO
Jablonksi (Dora Mae) and John L. Jablonski, Jr. As
Special Administrator and Personal Representative
Of the Estate of John L. Jablonski, Sr. vs. Ford
Motor Company and Natalie S. Ingram
Case No.: 03-L-2027
Law Firm: Dykema Gossett, Bloomfield Hills, MI

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Trial Testimony
May 3, 2005, Chicago, IL
Chevez, Martha et al v. Ford Motor Company,
Jojet Viray Pilao, Sotero Pilao, Fermin Rovira; and
Does 1 to 200
Case No. EC032707
Law Firm: Bowman and Brooke, Minneapolis, MN
Deposition (Supplemental) Testimony

June 1, 2005, Chicago, IL
Smith (Micky) and J. Scott Brown as representatives
of the Estate of Elizabeth Ashley Smith, Deceased
and the Estate of Noah Scott Smith, Deceased;
and J. Scott Brown as representative of the Estate
of Thomas Ashton Brown, Deceased, Plaintiffs, and
Marcus Allen Austin, Executor of the Estates of Milton
Andrew Austin and Thelma Susie Austin, Intervenors-
Plaintiffs v. Ford Motor Company; Reynolds Ford, Inc.;
And Five Star Ford, Inc.
Case No. CJ-2004-59
Law Firm: Eldridge Cooper Steichen & Leach, Tulsa, OK
Deposition Testimony

June 8, 2005, Kansas City, MO
Newton (Shonnie) et al. v. Ford Motor Company et al.
Nolte (Michael and Barbie) v. Ford Motor Company and
Trade Winds Distributing, Inc.
Case No. 03CV215677
Law Firm: Dykema Gossett, Bloomfield Hills, MI
Trial Testimony

July 6, 2005, Oakbrook Terrace, IL
Frede (Alicia and Jason) v Bridgestone/Firestone, Inc.;
Ford Motor Company; Pundmann Motor Company
Case No. 022-09936
Law Firm: Snell & Wilmer, Phoenix, AZ
Deposition Testimony

July 21, 2005, Naperville, IL
Eldridge, Savannah Georgia and David Eldridge,
as Personal Representative of the Estate of
Matthew Eldridge, Plaintiffs v. The Estate of
Robert J. Moore II, Deceased and 3CI Complete
Compliance Corporation d/b/a American 3CI,
Ford Motor Company and Taggart Motor Company,
Defendants
Case No. 03-5-12120
Law Firm: Prichard Hawkins McFarland and Young, San Antonio, TX
Deposition Testimony

August 9, 2005, Lisle, IL
Caudill (Ronald and Jewell) parents and next friends of
Jacob Caudill, a minor v. Amy Lea Sunday and Ford Motor Company
Case No. CJ-2002-070
Law Firm: Shook Hardy & Bacon, Kansas City, MO

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Deposition Testimony

August 22, 2005, Pensacola, FL
Adams (Pamela) v. Key Ford, Inc. and
Ford Motor Company
Case No. 98-1000-CA-01 (Div. B)
Law Firm: Cabaniss, Smith, Toole & Wiggins, Maitland, FL
Trial Testimony

September 1, 2005, Norman, OK
Smith (Micky) and J. Scott Brown as representatives
of the Estate of Elizabeth Ashley Smith, Deceased
and the Estate of Noah Scott Smith, Deceased;
and J. Scott Brown as representative of the Estate
of Thomas Ashton Brown, Deceased, Plaintiffs, and
Marcus Allen Austin, Executor of the Estates of Milton
Andrew Austin and Thelma Susie Austin, Intervenors-
Plaintiffs v. Ford Motor Company; Reynolds Ford, Inc.;
And Five Star Ford, Inc.
Case No. CJ-2004-59
Law Firm: Eldridge Cooper Steichen & Leach, Tulsa, OK
Trial Testimony

September 7, 2005, Norman, OK
Smith (Micky) and J. Scott Brown as representatives
of the Estate of Elizabeth Ashley Smith, Deceased
and the Estate of Noah Scott Smith, Deceased;
and J. Scott Brown as representative of the Estate
of Thomas Ashton Brown, Deceased, Plaintiffs, and
Marcus Allen Austin, Executor of the Estates of Milton
Andrew Austin and Thelma Susie Austin, Intervenors-
Plaintiffs v. Ford Motor Company; Reynolds Ford, Inc.;
And Five Star Ford, Inc.
Case No. CJ-2004-59
Law Firm: Eldridge Cooper Steichen & Leach, Tulsa, OK
Trial Testimony (Rebuttal)

September 21, 2005, Bristow, OK
Caudill (Ronald and Jewell) parents and next friends of
Jacob Caudill, a minor v. Amy Lea Sunday and Ford Motor Company
Case No. CJ-2002-070
Law Firm: Shook Hardy & Bacon, Kansas City, MO
Trial Testimony

September 23, 2005, Chicago, IL
Certain Automated Mechanical Transmission Systems for
Medium-Duty and Heavy-Duty Trucks and Components
Thereof
Case No.: U.S. International Trade Commission Investigation No. 337-TA-503
Law Firm: Sughrue Mion PLLC, Washington DC
Deposition Testimony

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September 25, 2005, Naperville, IL
Jenkins (Johnny Darryl) vs. Ford Motor Company, et al.
Jenkins (Paula Knight) vs. Ford Motor Company, et al.
Case No.: CV-04-114
Law Firm: Huie, Fernambucq & Stewart, Birmingham, AL
Deposition Testimony

September 29, 2005, Montgomery, AL
Hardy (Richard M.) V. U.S. Foodservice, Inc., formerly
PYA/Monarch, Inc., a Corporation, The Raymond Corporation,
a corporation, et al.
Case No. CV-02-1239-R
Law Firm: Lightfoot Franklin & White LLC, Birmingham, AL
Trial Testimony

October 3, 2005, Washington DC
Paice LLC vs. Toyota Motor Corporation,
Toyota Motor North America, Inc., and
Toyota Motor Sales USA, Inc.
Case No. 2-04CV-211 (DF)
Law Firm: Kenyon & Kenyon, Washington DC
Deposition Testimony

October 7, 2005, Washington DC
Certain Automated Mechanical Transmission Systems for
Medium-Duty and Heavy-Duty Trucks and Components
Thereof
Case No.: U.S. International Trade Commission Investigation No. 337-TA-503
Law Firm: Sughrue Mion PLLC, Washington DC
Trial Testimony

October 21, 2005, Lisle, IL
Howell, et al v. Ford Motor Company
Case No.: 04 CVS 107
Law Firm: Dykema Gossett, PLLC, Bloomfield Hills, MI
Deposition Testimony

November 15, 2005, Wheaton, IL
Korpela-Jorgenson (Dylan), C.M. Bye, Linda Jorgenson,
And Kids Care of Michigan v. Ford Motor Company, and
Samantha Elliott
Case No.: 04-CV-306
Law Firm: Donohue, Brown, Mathewson & Smyth, Chicago, IL
Deposition Testimony

November 28, 2005, Chicago, IL
Metzger (Leo A.) v. CNH America LLC, et al
Case No. 04C50446
Law Firm: Sughrue Mion PLLC, Washington DC
Deposition Testimony

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Testimony Record

December 5, 2005, York, PA
Keller (Christine) v The Raymond Corporation and
Pengate Handling Systems, Inc.
Case No. 97-SU-03400-01
Law Firm: Lavin, O'Neil Ricci Cedrone & DiSipio, Philadelphia, PA
Trial Testimony

December 6, 2005, Athens, GA
Gibson (Artumus) Jr. as Surviving Spouse of
Anne Marie Gibson, Deceased, and Artumus G. Gibson, Jr., as
Administrator of the Estate of Anne Marie Gibson, Deceased v.
Ford Motor Company, Draw-Tite, Inc., and William M. Burns, III
Case No. Civil Action No. ST-00-CV-0111
Law Firm: McGuire Woods Ross & Hardies, Richmond, VA
Trial Testimony

December 15-16, 2005, Marshall, TX
Paice LLC vs. Toyota Motor Corporation,
Toyota Motor North America, Inc., and
Toyota Motor Sales USA, Inc.
Case No. 2-04CV-211 (DF)
Law Firm: Kenyon & Kenyon, Washington DC
Trial Testimony

December 28, 2005, Chicago, IL
Williams (Shanti) as Personal Representative of the Estate
Of Roneshea Knight, deceased, Plaintiff, vs.
The General Tire and Rubber Company, a foreign corporation,
Continental Tire North America, Inc., a foreign corporation
formerly known as General Tire, Inc., ("CTNA"), Century
Products, Graco Children's Products, Inc., a foreign
corporation, f/k/a Century Car Seats and Car Credit,
a Florida corporation, and Sears Roebuck and Company, a
Foreign corporation, Defendants.
Pilcher (Lloyd) Plaintiff, vs. Gencorp, Inc., a foreign corporation,
The General Tire and Rubber Company, a foreign corporation,
Continental Tire North America, Inc., a foreign corporation
formerly known as General Tire, Inc., Car Credit, a Florida
Corporation, and Sears Roebuck and Company, a foreign
Corporation, Defendants.
Case No.: 04-2824
Law Firm: Arnstein & Lehr, West Palm Beach, FL
Deposition Testimony

January 10, 2006, Warrenville, IL
Felipe (Julian) v Ford Motor Company, Inc., a Delaware Corporation;
And Seagate Auto Brokers, Inc., a Florida Corporation
Case No. 04-3864 CA 04
Law Firm: Carlton Fields, P.A., Miami, Florida
Deposition Testimony

January 19, 2006, Rosemont, IL
Bynum (William D.) and Carolyn v. Ford Motor Company, et al.
Case No. CV-2001-202-CV12
Law Firm: Cabaniss, Smith, Toole & Wiggins, Maitland, FL

Edward M. Caulfield, Ph.D., P.E
Testimony Record

Deposition Testimony
February 9, 2006, New York City, NY
Adams (Walter) v. Richard Rathe, Robert Rathe,
Genie Industries, Inc., and Genie Industries, Inc.
Case No. 116382/00
Law Firm: Wilson, Elser, Moskowitz, Edelman
& Dicker LLP, White Plains, NY
Trial Testimony

February 17, 2006, Downers Grove, IL
Clayton (Dee) et al v Utah Auto Collections,
Warner Super Ford Store, Ford Motor Company
Case No. 000909522
Law Firm: Snell & Wilmer, Salt Lake City, UT
Deposition Testimony

March 7, 2006, Chicago, IL
Torres (Tania Cameal), Individually, and as
Administratrix of the Estate of Ricardo Torres,
Deceased, Plaintiff, v. Ford Motor Company,
TRW, Inc., TRW Vehicle Safety Systems, Inc.,
Boomershine Ford, Inc., and Atlanta/Southern Gold, Inc.,
d/b/a Southern Comfort Restaurant & Lounge
Case No.: 00VS-008220-H
Law Firm: McKenna, Long & Aldridge, Atlanta, GA
Deposition Testimony

March 22, 2006, Wheaton, IL
Dewinne (Rene B. Jr.), Plaintiff v.
The Raymond Corporation, N.J. Malin Holding, Inc., and
Home Depot, USA, Defendant
Case No.: GN 401898
Law Firm: Fulbright & Jaworski, San Antonio, TX
Deposition Testimony

May 4, 2006, Naperville, IL
Knuckles (Hattie), as Guardian Ad Litem for Robert H. Knuckles,
And Individually, Plaintiffs, v. Toyota Motor Corporation,
Toyota Motor Sales USA, Inc., Tokai Rika Co. Ltd., and
Signal Imports, Inc., Defendants
Case No. 2004-CP-42-201
Case No. 2004-CP-42-200
Law Firm: Nelson Mullins Riley & Scarborough, Atlanta, GA
Deposition Testimony

May 16, 2006, Chicago, IL
Eaton Corporation, Plaintiff, v.
ZF Meritor LLC, Arvinmeritor, Inc. and
ZF Friedrichshafen AG, Defendants
Case No. 03-74844
Law Firm: Sughrue Mion Zinn et. al., Washington DC
Deposition Testimony

Edward M. Caulfield, Ph.D., P.E
Testimony Record

May 24, 2006, Chicago, IL
Eaton Corporation, Plaintiff, v.
ZF Meritor LLC, Arvinmeritor, Inc. and
ZF Friedrichshafen AG, Defendants
Case No. 03-74844
Law Firm: Sughrue Mion Zinn et. al., Washington DC
Deposition Testimony (continued)

May 26, 2006, Los Angeles, CA
Delloro (Winfred and Celina), Plaintiffs, vs.
Enterprise Rent-A-Car of Los Angeles, a Nevada Corporation, et al.
(General Motors)
Case No. BC328314
Law Firm: Dykema Gossett, LLP, Los Angeles, CA
Deposition Testimony

June 7, 2006, Lisle, IL
Early (David), Administrator of the Estate of
Joshua Early, Deceased and Karen Mullins,
Administratix of the Estate of Timothy Mullins,
Deceased
Case No. 3:04-CV-251-5
Law Firm: Woodward Hobson & Fulton LLP, Louisville, KY
Deposition Testimony

June 30, 2006, Aurora, IL
Dolan (Kathleen), Individually and as
Personal Representative of the Estate
Of Mary Anne Torpey, Deceased,
Joan Gorman, Bonnie Polt, Individually
And as Next Friend of Glen Polt, Jr.,
Glen Polt and Kristin Polt, Plaintiffs,
v. Ford Motor Company, Inc., Jerome Duncan
(Ford Dealership) and Peggy Thompson,
Defendants
Case No. 04-3074-N1
Law Firm: Bowman and Brooke, Minneapolis, MN

August 9, 2006, Los Angeles, CA
Delloro (Winfred and Celina), Plaintiffs, vs.
Enterprise Rent-A-Car of Los Angeles, a Nevada Corporation, et al.
(Michelin North America Inc.)
Case No. BC328314
Law Firm: Yukevich Calfo & Cavanaugh, Los Angeles, CA
Trial Testimony

August 29, 2006, Washington DC
Eaton Corporation, Plaintiff, v.
ZF Meritor LLC, Arvinmeritor, Inc. and
ZF Friedrichshafen AG, Defendants
Case No. 03-74844
Law Firm: Sughrue Mion Zinn et. al., Washington DC
Hearing Testimony

Edward M. Caulfield, Ph.D., P.E
Testimony Record

September 12, 2006, Wheaton, IL
Borsack (Ronald), Individually and as Administrator of
The Estate of Lesley Borsack, Plaintiff, against
Ford Motor Company, a Delaware Corporation,
Defendant
Case No. 04-CV-3255
Law Firm: Aaronson, Rappaport, Feinstein & Deutsch, LLP, New York NY
Deposition Testimony

September 14, 2006, Irvine, CA
Justice (Gloria), Plaintiff, vs. Clark County Airlife,
Ford Motor Company, etc., et al., Defendants
Case No. BCV 06005
Law Firm: Snell & Wilmer, Costa Mesa, CA
Deposition Testimony

September 22, 2006, Wheaton, IL
Allison (Shannon) et al v. Ford Motor Company
Case No. CV-2005-668
Law Firm: Snell and Wilmer, Salt Lake City, UT
Deposition Testimony

October 19-20, 2006, Lisle, IL
Certain Combination Motor and Transmission
Systems and Devices Used Therein, and
Products Containing the Same
(Solomon Technologies v Toyota Motor Corporation),
U.S. International Trade Commission Investigation No. 337-TA-561
Law Firm: Finnegan, Henderson et al, Washington DC
Deposition Testimony

November 9-10, 2006, Washington DC
Certain Combination Motor and Transmission
Systems and Devices Used Therein, and
Products Containing the Same
(Solomon Technologies v Toyota Motor Corporation),
U.S. International Trade Commission Investigation No. 337-TA-561
Law Firm: Finnegan, Henderson et al, Washington DC
Trial Testimony

December 7, 2006, Clinton Township, MI
Dolan (Kathleen), Individually and as
Personal Representative of the Estate
Of Mary Anne Torpey, Deceased,
Joan Gorman, Bonnie Polt, Individually
And as Next Friend of Glen Polt, Jr.,
Glen Polt and Kristin Polt, Plaintiffs,
v. Ford Motor Company, Inc., Jerome Duncan
(Ford Dealership) and Peggy Thompson,
Defendants
Case No. 04-3074-N1
Law Firm: Bowman and Brooke, Minneapolis, MN
Trial Testimony

Edward M. Caulfield, Ph.D., P.E
Testimony Record

December 20, 2006, San Francisco, CA
Pitts v. Ford
Case No. FCS026087
Law Firm: Bowman & Brooke, San Jose, CA
Deposition

January 4, 2007, Naperville, Illinois
Lum v. Mercedes Benz
Case No. 3:05 CV7191
Law Firm: Carroll Burdick & McDonough, San Francisco, CA
Deposition

January 9, 2007, Natchez, Mississippi
Yancy (Raymond) v. Ford Motor Company, Inc.
Case No. 02-KV-0272S
Law Firm: McGuire Woods, Richmond Virginia
Deposition

EX-3

Designation: D 2240 – 03

Standard Test Method for Rubber Property—Durometer Hardness[1]

This standard is issued under the fixed designation D 2240; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

This standard has been approved for use by agencies of the Department of Defense.

1. Scope

1.1 This test method describes twelve types of rubber hardness measurement devices known as durometers: Types A, B, C, D, DO, E, M, O, OO, OOO, OOO-S, and R. The procedure for determining indentation hardness of substances classified as thermoplastic elastomers, vulcanized (thermoset) rubber, elastomeric materials, cellular materials, gel-like materials and some plastics is also described.

1.2 This test method is not equivalent to other indentation hardness methods and instrument types, specifically those described in Test Method D 1415.

1.3 This test method is not applicable to the testing of coated fabrics.

1.4 The values stated in SI units are to be regarded as standard. The values given in parentheses are for information only. Many of the stated dimensions in SI are direct conversions from the U. S. Customary System to accommodate the instrumentation, practices and procedures that existed prior to the Metric Conversion Act of 1975.

1.5 All materials, instruments, or equipment used for the determination of mass, force or dimension shall have traceability to the National Institute for Standards and Technology, or other internationally recognized organization parallel in nature.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 374 Test Methods for Thickness of Solid Electrical Insulation[2]

D 618 Practice for Conditioning Plastics for Testing[3]

D 785 Test Method for Rockwell Hardness of Plastics and Electrical Insulating Materials[3]

D 1349 Practice for Rubber—Standard Temperatures For Testing[4]

D 1415 Test Method for Rubber Property—International Hardness[4]

D 4483 Practice for Determining Precision for Test Method Standards in the Rubber and Carbon Black Industries[4]

F 1957 Test Method for Composite Foam Hardness-Durometer Hardness[5]

2.2 *ISO Standards:*

ISO/IEC 17025: 1999 General Requirements for the Competence of Testing and Calibration Laboratories[6]

3. Summary of Test Method

3.1 This test method permits hardness measurements based on either initial indentation or indentation after a specified period of time, or both. Durometers with maximum reading indicators used to determine maximum hardness values of a material may yield lower hardness when the maximum indicator is used.

3.2 The procedures for Type M, or micro hardness durometers, accommodate specimens that are, by their dimensions or configuration, ordinarily unable to have their durometer hardness determined by the other durometer types described. Type M durometers are intended for the testing of specimens having a thickness or cross sectional diameter of 1.25 mm (0.050 in.) or greater, although specimens of lesser dimensions may be successfully accommodated under the conditions specified in Section 6, and have a Type M durometer hardness range of between 20 and 90. Those specimens which have a durometer hardness range other than specified shall use another suitable procedure for determining durometer hardness.

4. Significance and Use

4.1 This test method is based on the penetration of a specific type of indentor when forced into the material under specified conditions. The indentation hardness is inversely related to the penetration and is dependent on the elastic modulus and viscoelastic behavior of the material. *The geometry of the*

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[1] This test method is under the jurisdiction of ASTM Committee D11 on Rubber and is the direct responsibility of Subcommittee D11.10 on Physical Testing.

Current edition approved May 10, 2003. Published May 2003. Originally approved in 1964. Last previous edition approved in 2002 as D 2240 – 02b.

[2] *Annual Book of ASTM Standards*, Vol 10.01.

[3] *Annual Book of ASTM Standards*, Vol 08.01.

[4] *Annual Book of ASTM Standards*, Vol 09.01.

[5] *Annual Book of ASTM Standards*, Vol 15.07.

[6] Available from International Organization for Standardization (ISO), 1 rue de Varembé, Case postale 56, CH-1211, Geneva 20, Switzerland.

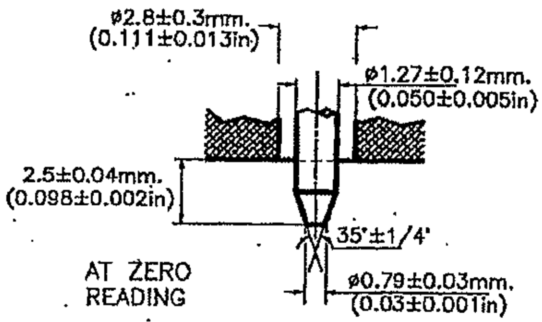

FIG. 1 (a) Type A and C Indentor

indentor and the applied force influence the measurements such that no simple relationship exists between the measurements obtained with one type of durometer and those obtained with another type of durometer or other instruments used for measuring hardness. This test method is an empirical test intended primarily for control purposes. No simple relationship exists between indentation hardness determined by this test method and any fundamental property of the material tested. For specification purposes it is recommended that Test Method D 785 be used for materials other than those described in 1.1.

5. Apparatus

5.1 *Hardness measuring apparatus, or durometer, and an operating stand,* Type 1, Type 2, or Type 3 (see 5.1.2) consisting of the following components:

5.1.1 *Durometer:*

5.1.1.1 *Presser Foot,* the configuration and the total area of a durometer presser foot may produce varying results when there are significant differences between them. It is recommended that when comparing durometer hardness determinations of the same type (see 4.1), that the comparisons be between durometers of similar presser foot configurations and total area, and that the presser foot configuration and size be noted in the Hardness Measurement Report (see 10.2.4 and 5.1.1.3).

5.1.1.2 *Presser Foot,* Types A, B, C, D, DO, E, O, OO, OOO, and OOO-S, with an orifice (to allow for the protrusion of the indentor) having a diameter as specified in Fig. 1 (a, b, c, d, e, f, and g), with the center a minimum of 6.0 mm (0.24 in.) from any edge of the foot. When the presser foot is not of a flat circular design, the area shall not be less than 500 mm^2 (19.7 in^2).[7]

NOTE 1—The Type OOO and the Type OOO-S, designated herein, differ in their indentor configuration, spring force, and the results obtained. See Table 1 and Fig. 1 (e and g).

5.1.1.3 *Presser Foot*—flat circular designs designated as Type *xR*, where *x* is the standard durometer designation and *R* indicates the flat circular press foot described herein, for example, Type *aR*, *dR*, etc. The presser foot, having a centrally located orifice (to allow for the protrusion of the indentor) of a diameter as specified in Fig. 1 (a through g). The flat circular presser foot shall be 18 ± 0.5 mm (0.71 ± 0.02 in.) in diameter. These durometer types shall be used in an operating stand (see 5.1.2).

(a) Durometers having a presser foot configuration other than that indicated in 5.1.1.3 shall not use the Type *xR* designation, and it is recommended that their presser foot configuration and size be stated in the Hardness Measurement Report (see 10.2.4).

5.1.1.4 *Presser Foot, Type M,* with a centrally located orifice (to allow for the protrusion of the indentor), having a diameter as specified in Fig. 1 (d), with the center a minimum of 1.60 mm (0.063 in.) from any edge of the flat circular presser foot. The Type M durometer shall be used in a Type 3 operating stand (see 5.1.2.4).

5.1.1.5 *Indentor,* formed from steel rod and hardened to 500 HV10 and shaped in accordance with Fig. 1 (a, b, c, d, e, or g), polished over the contact area so that no flaws are visible under 20× magnification, with an indentor extension of 2.50 ± 0.04 mm (0.098 ± 0.002 in.).

5.1.1.6 *Indentor, Type OOO-S,* formed from steel rod and hardened to 500 HV10, shaped in accordance with Fig. 1 (f), polished over the contact area so that no flaws are visible under 20× magnification, with an indentor extension of 5.00 ± 0.04 mm (0.198 ± 0.002 in.).

5.1.1.7 *Indentor, Type M,* formed from steel rod and hardened to 500 HV10 and shaped in accordance with Fig. 1 (d), polished over the contact area so that no flaws are visible under 50× magnification, with an indentor extension of 1.25 ± 0.02 mm (0.049 ± 0.001 in.).

5.1.1.8 *Indentor Extension Indicator,* analog or digital electronic, having a display that is an inverse function of the indentor extension so that:

(a) the display shall indicate from 0 to 100 with no less than 100 equal divisions throughout the range at a rate of one hardness point for each 0.025 mm (0.001 in.) of indentor movement,

(b) the display for Type OOO-S durometers shall indicate from 0 to 100 with no less than 100 equal divisions throughout the range at a rate of one hardness point for each 0.050 mm (0.002 in.) of indentor movement,

[7] The Type OOO-S, manufactured by the Shore Instrument Company, Division of Instron Corporation, Canton, MA, was previously designated as Type OOO.

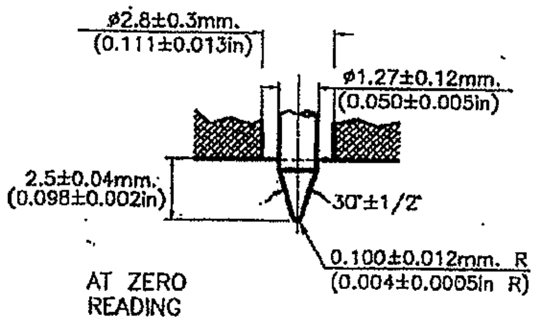

FIG. 1 (b) Type B and D Indentor *(continued)*

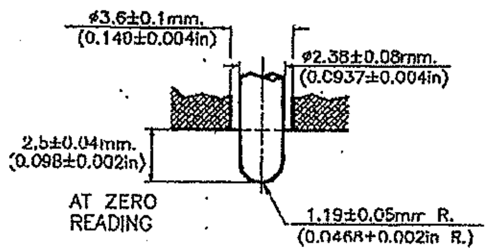

FIG. 1 (c) O, DO, and OO Indentor *(continued)*

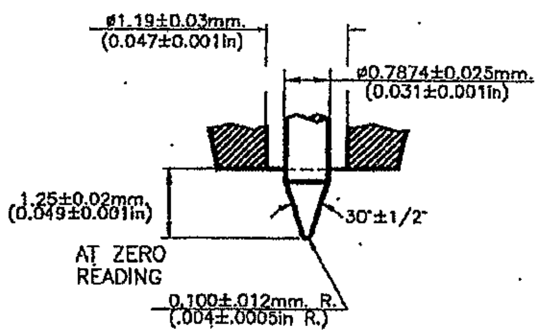

FIG. 1 (d) Type M Indentor *(continued)*

(c) the display for Type M durometers shall indicate from 0 to 100 with no less than 100 equal divisions at a rate of one hardness point for each 0.0125 mm (0.0005 in.) of indentor movement, and

(d) in the case of analog dial indicators having a display of 360°, the points indicating 0 and 100 may be at the same point on the dial and indicate 0, 100, or both.

5.1.1.9 *Timing Device (optional)*, capable of being set to a desired elapsed time, signaling the operator or holding the hardness reading when the desired elapsed time has been reached. The timer shall be automatically activated when the presser foot is in contact with the specimen being tested, for example, the initial indentor travel has ceased. Digital electronic durometers may be equipped with electronic timing devices that shall not affect the indicated reading or determinations attained by more than one-half of the calibration tolerance stated in Table 1.

5.1.1.10 *Maximum indicators (optional)*, maximum indicating pointers are auxiliary analog indicating hands designed to remain at the maximum hardness value attained until reset by

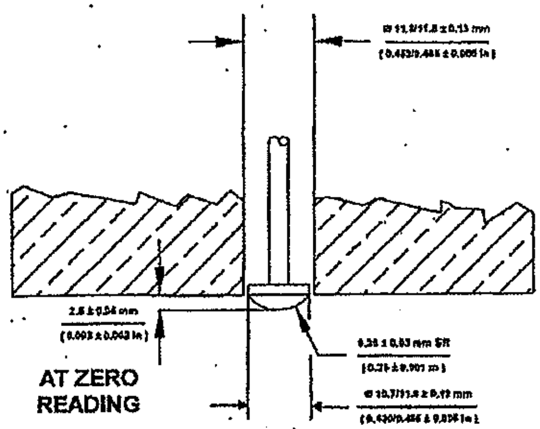

FIG. 1 (e) Type OOO Indentor *(continued)*

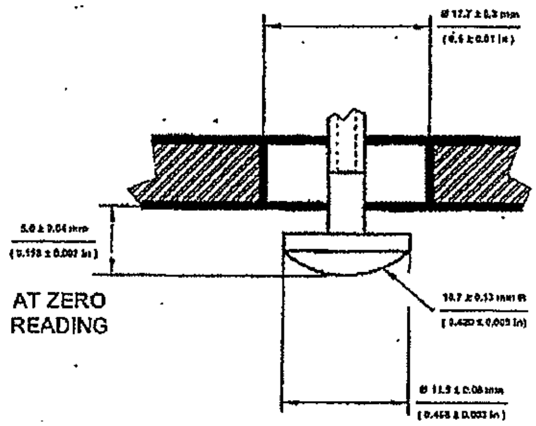

FIG. 1 (f) Type OOO-S Indentor *(continued)*

the operator. Electronic maximum indicators are digital displays electronically indicating and maintaining the maximum value hardness valued achieved until reset by the operator.

5.1.1.11 Analog maximum indicating pointers have been shown to have a nominal effect on the values attained, however, this effect is greater on durometers of lesser total mainspring loads, for example, the effect of a maximum indicating pointer on Type D durometer determinations will be less than those determinations achieved using a Type A durometer. Analog style durometers may be equipped with maximum indicating pointers. The effect of a maximum indicating pointer shall be noted at the time of calibration in the calibration report (see 10.1.5), and when reporting hardness determinations (see 10.2.4). Analog Type M, OO, OOO, and Type OOO-S durometers shall not be equipped with maximum indicating pointers.

5.1.1.12 Digital electronic durometers may be equipped with electronic maximum indicators that shall not affect the indicated reading or determinations attained by more than one half of the spring calibration tolerance stated in Table 1.

5.1.1.13 *Calibrated Spring*, for applying force to the indentor, in accordance with Fig. 1 (a through g) and capable of applying the forces as specified in Table 1.

5.1.2 *Operating Stand* (Fig. 2):

5.1.2.1 Type 1, Type 2, and Type 3, shall be capable of supporting the durometer presser foot surface parallel to the specimen support table (Fig. 3) throughout the travel of each. The durometer presser foot to specimen support table parallelism shall be verified each time the test specimen support table is adjusted to accommodate specimens of varying dimensions. This may be accomplished by applying the durometer presser foot to the point of contact with the specimen support table and making adjustments by way of the durometer mounting assembly or as specified by the manufacturer.

5.1.2.2 *Operating Stand, Type 1* (specimen to indentor type), shall be capable of applying the specimen to the indentor in a manner that minimizes shock.

5.1.2.3 *Operating Stand, Type 2* (indentor to specimen type), shall be capable of controlling the rate of descent of the indentor to the specimen at a maximum of 3.20 mm/s (0.125

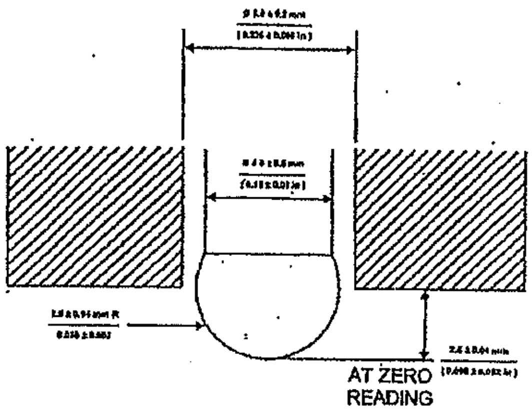

FIG. 1 (g) Type E Indentor *(continued)*

TABLE 1 Durometer Spring Force Calibration[A]
All Values are in N

Indicated Value	Type A, B, E, O	Type C, D, DO	Type M	Type OO, OOO	Type OOO-S
0	0.55	0	0.324	0.203	0.167
10	1.3	4.445	0.368	0.294	0.343
20	2.05	8.89	0.412	0.385	0.520
30	2.8	13.335	0.456	0.476	0.696
40	3.55	17.78	0.5	0.566	0.873
50	4.3	22.225	0.544	0.657	1.049
60	5.05	26.67	0.589	0.748	1.226
70	5.8	31.115	0.633	0.839	1.402
80	6.55	35.56	0.677	0.93	1.579
90	7.3	40.005	0.721	1.02	1.755
100	8.05	44.45	0.765	1.111	1.932
N/durometer unit	0.075	0.4445	0.0044	0.00908	0.01755
Spring Calibration Tolerance	± 0.075 N	± 0.4445 N	± 0.0176 N	± 0.0182 N	± 0.0353 N

[A] Refer to 5.1.1.3 for the Type *xR* designation.

in/s) and applying a force sufficient to overcome the calibrated spring force as shown in Table 1.

5.1.2.4 *Operating Stand, Type 3* (indentor to specimen type), hydraulic dampening, pneumatic dampening or electro-mechanical (required for the operation of Type M durometers) shall be capable of controlling the rate of descent of the indentor to the specimen at a maximum of 3.2 mm/s (0.125 in/s) and applying a force sufficient to overcome the calibrated spring force as shown in Table 1. Manual application, Type 1 or Type 2 operating stands are not acceptable for Type M durometer operation.

5.1.2.5 The entire instrument should be plumb and level, and resting on a surface that will minimize vibration. Operating the instrument under adverse conditions will negatively affect the determinations attained.

5.1.2.6 *Specimen Support Table*, (Fig. 3) integral to the operating stand, and having a solid flat surface. The specimen support platform may have orifices designed to accept various inserts or support fixtures (Fig. 3) to provide for the support of irregularly configured specimens. When inserts are used to support test specimens, care must be taken to align the indentor to the center of the insert, or the point at which the indentor is to contact the specimen. Care should be exercised to assure that the indentor does not abruptly contact the specimen support table as damage to the indentor may result.

6. Test Specimen

6.1 The test specimen, herein referred to as "specimen" or "test specimen" interchangeably, shall be at least 6.0 mm (0.24 in.) in thickness unless it is known that results equivalent to the 6.0 mm (0.24 in.) values are obtained with a thinner specimen.

6.1.1 A specimen may be composed of plied pieces to obtain the necessary thickness, but determinations made on such specimens may not agree with those made on solid specimens as the surfaces of the plied specimens may not be in complete contact. The lateral dimensions of the specimen shall be sufficient to permit measurements at least 12.0 mm (0.48 in.) from any edge unless it is known that identical results are obtained when measurements are made at a lesser distance from an edge.

6.1.2 The surfaces of the specimen shall be flat and parallel over an area to permit the presser foot to contact the specimen over an area having a radius of at least 6.0 mm (0.24 in.) from the indentor point. The specimen shall be suitably supported to provide for positioning and stability. *A suitable hardness*

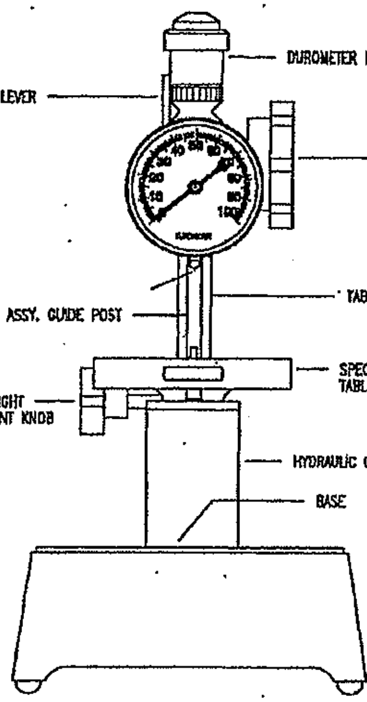

FIG. 2 Durometer Operating Stand

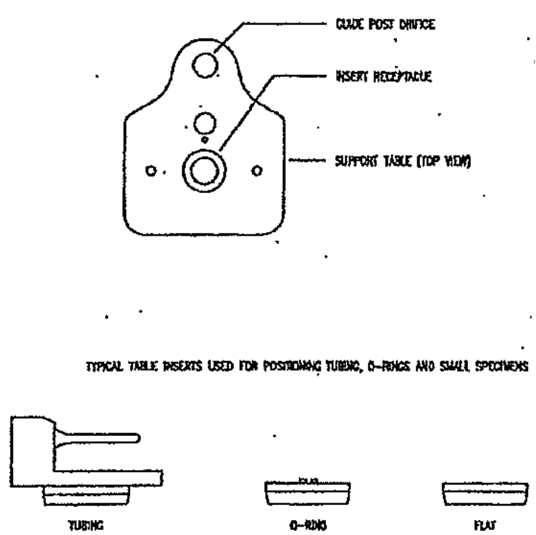

FIG. 3 Small Specimen Support Table

determination cannot be made on an uneven or rough point of contact with the indentor.

6.2 Type OOO, OOO-S, and M test specimens should be at least 1.25 mm (0.05 in.) in thickness unless it is known that results equivalent to the 1.25 mm (0.05 in.) values are obtained with a thinner specimen.

6.2.1 A Type M specimen that is not of a configuration described in 6.2.2 may be composed of plied pieces to obtain

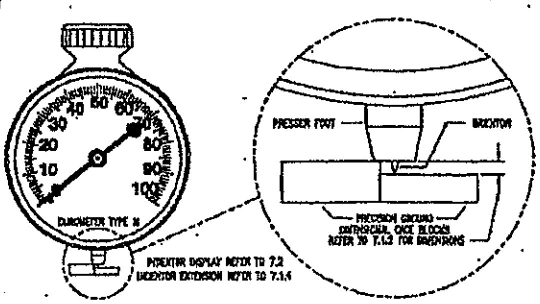

FIG. 4 Detail of Indentor Extension and Display Adjustment

the necessary thickness, but determinations made on such specimens may not agree with those made on solid specimens because the surfaces of the plied specimens may not be in complete contact. The lateral dimensions of the specimen should be sufficient to permit measurements at least 2.50 mm (0.10 in.) from any edge unless it is known that identical results are obtained when measurements are made at lesser distance from an edge. *A suitable hardness determination cannot be made on an uneven or rough point of contact with the indentor.*

6.2.2 The Type M specimen, when configured as an o-ring, circular band, or other irregular shape shall be at least 1.25 mm (0.05 in.) in cross sectional diameter, unless it is known that results equivalent to the 1.25 mm (0.05 in.) values are obtained with a thinner specimen. The specimen shall be suitably supported in a fixture (Fig. 3) to provide for positioning and stability.

6.3 The minimum requirement for the thickness of the specimen is dependent on the extent of penetration of the indentor into the specimen; for example, thinner specimens may be used for materials having higher hardness values. The minimum distance from the edge at which measurements may be made likewise decreases as the hardness increases.

7. Calibration

7.1 *Indentor Extension Adjustment Procedure:*

7.1.1 Place precision ground dimensional blocks (Grade B or better) on the support table and beneath the durometer presser foot and indentor. Arrange the blocks so that the durometer presser foot contacts the larger block(s) and the indentor tip just contacts the smaller block (Fig. 4). It is necessary to observe the arrangement of the blocks and the presser foot/indentor under a minimum of 20× magnification to assure proper alignment.

7.1.2 Indentor extension and shape shall be in accordance with 5.1.1.5, 5.1.1.6, or 5.1.1.7, respective to durometer type. See Fig. 1 (a through g). Examination of the indentor under 20× magnification, 50× for Type M indentors, is required to examine the indentor condition. Misshapen or damaged indentors shall be replaced.

7.1.3 A combination of dimensional gage blocks shall be used to achieve a difference of 2.54 + 0.00/–0.0254 mm (0.100 + 0.00/–0.001 in.) between them. For Type OOO-S durometers, the gage block dimensions are 5.08 + 0.00/–0.0508 mm (0.200 + 0.00/–0.002 in.). For Type M durometers, the gage block dimensions are 1.27 + 0.0/–0.0127 mm (0.050 + 0.00/–0.0005 in.) between them (Fig. 4).

7.1.4 Carefully lower the durometer presser foot until it contacts the largest dimensional block(s), the indentor tip should just contact the smaller block, verifying full indentor extension.

7.1.5 Adjust the indentor extension to 2.50 ± 0.04 mm (0.098 ± 0.002 in.). For Type OOO-S durometers, adjust the indentor extension to 5.0 ± 0.04 mm (0.198 ± 0.002 in.). For Type M durometers, adjust the indentor extension to 1.25 ± 0.02 mm (0.049 ± 0.001 in.), following the manufacturer's recommended procedure.

7.1.5.1 When performing the procedures in 7.1, care should be used so as not to cause damage to the indentor tip. Fig. 4 depicts a suitable arrangement for gauging indentor extension.

7.1.6 Parallelism of the durometer presser foot to the support surface, and hence the dimensional gage blocks, at the time of instrument calibration, may be in accordance with Test Method D 374, Machinist's Micrometers, or otherwise accomplished in accordance with the procedures specified by the manufacturer.

7.2 *Indentor Display Adjustment:*

7.2.1 After adjusting the indentor extension as indicated in 7.1, use a similar arrangement of dimensional gage blocks to verify the linear relationship between indentor travel and indicated display at two points: 0 and 100. Following the manufacturer's recommendations, make adjustments so that:

7.2.2 The indicator displays a value equal to the indentor travel measured to within:

–0.0 +1.0 durometer units measured at 0;

±0.50 durometer units measured at 100;

±1 durometer units at all other points delineated in 7.4.

7.2.3 Each durometer point indicated is equal to 0.025 mm (0.001 in.) of indentor travel, for Type M Durometers each indicated point is equal to 0.0125 mm (0.0005 in.).

7.2.4 The indicator shall not display a value greater than 100 or less than 0 at the time of calibration.

7.2.5 Other means of determining indentor extension or indentor travel, such as optical or laser measurement methods, are acceptable. The instrumentation used shall have traceability as described in 1.5.

7.2.6 The durometer shall be supported in a suitable fashion when performing the procedures described in 7.1 and 7.2.

7.3 *Calibration device:*

7.3.1 The durometer spring shall be calibrated by supporting the durometer in a calibrating device, refer to Fig. 5, in a vertical position and applying a measurable force to the indentor tip. The force may be measured by means of a balance as depicted in Fig. 5, or an electronic force cell. The calibrating device shall be capable of measuring applied force to within 0.5 % of the maximum spring force necessary to achieve 100 durometer units.

7.3.2 Care should be taken to ensure that the force is applied vertically to the indentor tip, as lateral force will cause errors in calibration. Refer to 7.1.5.1 and 7.1.6.

7.4 *Spring Calibration*—The durometer spring shall be calibrated at displayed readings of 10, 20, 30, 40, 50, 60, 70, 80, and 90. The measured force (9.8× mass in kilograms) shall

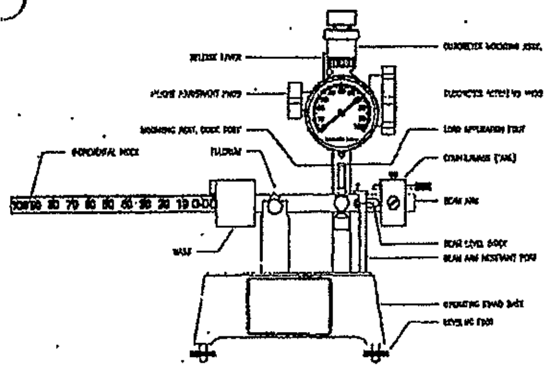

FIG. 5 Example of Durometer Calibration Apparatus

be within the spring calibration tolerance specified in Table 1. Table 1 identifies the measured force applied to the indentor for the entire range of the instrument, although it is necessary only to verify the spring calibration at points listed herein.

7.5 *Spring Calibration Procedure*:

7.5.1 Ensure that the indentor extension has been adjusted in accordance with 7.1 and the linear relationship between indentor travel and display is as specified in 7.2.

7.5.2 Place the durometer in the calibration device as depicted in Fig. 5. Apply the forces indicated in Table 1 so that forces applied are aligned with the centerline of the indentor in a fashion that eliminates shock or vibration and adjust the durometer according to manufacturers' recommendations so that:

7.5.3 At the points enumerated in 7.4, the display shall indicate a value equal to 0.025 mm (0.001 in.) of indentor travel. For Type OOO-S durometers, the display shall indicate a value equal to 0.05 mm (0.002 in.) of indentor travel. For Type M durometers, the display shall indicate a value equal to 0.0125 mm (0.0005 in.) of indentor travel within the spring calibration tolerances specified in 7.6.

7.6 Spring calibration tolerances are ±1.0 durometer units for Types A, B, C, D, E, O, and DO, ±2.0 durometer units for Types OO, OOO, and OOO-S, and ±4.0 durometer units for Type M, while not indicating below 0 or above 100 at the time of calibration (see Table 1).

7.7 *Spring Force combinations*:

For Type A, B, E, and O durometers:

Force, N = 0.55 + 0.075 HA

Where HA = hardness reading on Type A, B, E, and O durometers.

For Type C, D, and DO durometers:

Force, N = 0.4445 HD

Where HD = hardness reading on Type C, D, and DO durometers.

For Type M durometers:

Force, N = 0.324 + 0.0044 HM

Where HM = hardness reading on Type M durometers.

For Type OO and OOO durometers:

Force, N = 0.203 + 0.00908 HOO

Where HOO = hardness reading on Type OO durometers.

For Type OOO-S durometers:

Force, N = 0.167 + 0.01765 HOOO-S

Where HOOO-S = hardness reading on Type OOO-S durometers.

7.8 The rubber reference block(s) provided for checking durometer operation and state of calibration are not to be relied upon as calibration standards. The calibration procedures outlined in Section 7 are the only valid calibration procedures. The use of metal reference blocks is no longer recommended (see Note 2).

8. Laboratory Atmosphere and Test Specimen Conditioning

8.1 Tests shall be conducted in the standard laboratory atmosphere, as defined in Practice D 618, Section 4.2.

8.2 The instrument shall be maintained in the standard laboratory atmosphere, as defined in Practice D 618, Section 4.1, for 12 h prior to performing a test.

8.3 The specimen shall be conditioned in accordance with condition 40/23 exclusive of humidity control, as described in Practice D 618, Section 8.1, Procedure A and tested under the same conditions, exclusive of humidity control.

8.4 These procedures may be modified if agreed upon between laboratories or between supplier and user and are in accordance with alternative procedures identified in Practice D 618.

8.5 No conclusive evaluation has been made on durometers at temperatures other than 23.0 ± 2.0°C (73.4 ± 3.6°F). Conditioning at temperatures other than the above may show changes in calibration. Durometer use at temperatures other than the above should be decided locally (see Practice D 1349).

9. Procedure

9.1 *Operating Stand Operation (Type 3 Operating Stand Required for Type M)*:

9.1.1 Care shall be exercised to minimize the exposure of the instrument to environmental conditions that are adverse to the performance of the instrument, or adversely affect test results.

9.1.2 Adjust the presser foot to support table parallelism as described in 5.1.2.1. It is necessary to make this adjustment each time the support table is moved to accommodate specimens of varying dimensions.

9.1.3 Prior to conducting a test, adjust the vertical distance from the presser foot to the contact surface of the test specimen to 25.4 ± 2.5 mm (01.00 ± 0.100 in.), unless it is known that identical results are obtained with presser foot at a greater or lesser vertical distance from the test specimen contact surface, or if otherwise stipulated by the manufacturer.

9.1.4 Place the specimen on the specimen support table, in a manner that the contact point of the indentor is in accordance with Section 6, unless it is known that identical results are obtained when measurements are made with the indentor at a lesser distance from the edge of the test specimen.

9.1.5 Actuate the release lever (Fig. 2) of the operating stand or activate the electromechanical device, allowing the durometer to descend at a controlled rate and apply the presser foot to the specimen in accordance with 5.1.2. In the case of "specimen to indentor" type operating stands, operate the lever

or other mechanism to apply the specimen to the indentor in a manner that assures parallel contact of the specimen to the durometer presser foot without shock and with just sufficient force to overcome the calibrated spring force as shown in Table 1.

9.1.6 An operating stand that applies the mass at a controlled rate of descent, without shock is mandatory for Type M durometers. Hand held application or the use of a Type 1 or Type 2 operating stands for the Type M durometer is not an acceptable practice, refer to 5.1.2.4.

9.1.7 For any material covered in 1.1, once the presser foot is in contact with the specimen, for example, the initial indentor travel has ceased, the indicated reading shall be recorded within 1 ± 0.1 s, or after any period of time agreed upon among laboratories or between supplier and user. If the durometer is equipped with a maximum indicator, the maximum indicated reading shall be recorded within 1 ± 0.1 s of the cessation of indentor travel. The indicated hardness reading may change with time.

[redacted]

9.1.8 Make five determinations of hardness at different positions on the specimen at least 6.0 mm (0.24 in.) apart, 0.80 mm (0.030 in.) apart for Type M; and calculate the arithmetic mean, or alternatively calculate the median. The means of calculating the determinations shall be reported according to 10.2.8

9.2 *Manual (Hand Held) Operation of Durometer*:

9.2.1 Care shall be exercised to minimize the exposure of the instrument to environmental conditions that are adverse to the performance of the instrument, or adversely affect test results.

9.2.2 Place the specimen on a flat, hard, horizontal surface. Hold the durometer in a vertical position with the indentor tip at a distance from any edge of the specimen as described in Section 6, unless it is known that identical results are obtained when measurements are made with the indentor at a lesser distance.

9.2.3 Apply the presser foot to the specimen, maintaining it in a vertical position keeping the presser foot parallel to the specimen, with a firm smooth downward action that will avoid shock, rolling of the presser foot over the specimen, or the application of lateral force. Apply sufficient pressure to assure firm contact between the presser foot and the specimen.

9.2.4 For any material covered in 1.1, after the presser foot is in contact with the specimen, the indicated reading shall be recorded within 1 ± 0.1 s, or after any period of time agreed upon among laboratories or between supplier and user. If the durometer is equipped with a maximum indicator, the maximum indicated reading shall be recorded within 1 ± 0.1 s of the cessation of initial indentor travel. The indicated hardness reading may change with time.

9.2.5 Make five determinations of hardness at different positions on the specimen at least 6.0 mm (0.24 in.) apart and calculate the arithmetic mean, or alternatively calculate the median. The means of calculating the determinations shall be reported according to Section 10.2.8.

9.3 It is acknowledged that durometer readings below 20 or above 90 are not considered reliable. It is suggested that readings in these ranges not be recorded.

TABLE 2 Type 1 Precision—Type M Durometer Method

Material	Within Laboratories				Between Laboratories		
	MEAN	Sr^A	r^B	$(r)^C$	SR^D	R^E	$(R)^F$
1	31.8	1.26	3.58	11.24	3.76	10.83	33.41
2	40.8	1.14	3.23	7.90	2.47	7.00	17.13
3	54.0	0.976	2.76	5.11	2.38	6.73	12.46
4	62.8	0.782	2.21	3.52	2.24	6.34	10.10
5	70.9	0.709	2.01	2.83	0.974	2.76	3.89
6	80.6	1.686	4.77	5.92	1.61	4.56	5.65
7	87.7	1.16	3.25	3.71	2.63	7.45	8.60
8	32.4	0.947	2.68	8.26	3.64	10.29	31.73
9	41.8	0.797	2.26	5.40	2.23	6.31	15.11
10	53.3	0.669	1.89	3.55	2.29	6.49	12.17
11	63.2	0.485	1.37	2.17	2.19	6.20	9.80
12	69.6	0.737	2.09	3.00	0.99	2.80	4.02
13	78.3	0.784	2.22	2.84	1.04	2.94	3.75
14	87.6	1.121	3.17	3.62	2.65	7.49	8.65
15	34.1	0.85	2.40	7.05	1.84	5.20	16.25
16	42.3	0.635	1.80	4.26	1.20	3.39	8.01
17	54.8	0.58	1.59	2.90	2.15	6.09	11.15
18	62.9	1.12	3.17	5.04	1.47	4.16	6.61
19	70.3	0.689	1.95	2.77	0.944	2.67	3.80
20	81.7	0.483	1.37	1.67	1.10	3.10	3.80
21	87.9	0.879	2.49	2.83	2.07	5.86	6.67
AVERAGE	61.4						
POOLED VALUES		0.924	2.62	4.28	2.148	6.07	9.89

[A] Sr = repeatability standard deviation, measurement units.
[B] r = repeatability = 2.83 × Sr, measurement units.
[C] (r) = repeatability, relative, (that is, in percent).
[D] SR = reproducibility standard deviation, measurement units.
[E] R = reproducibility = 2.83 × SR, measurement units.
[F] (R) = reproducibility, relative, (that is, in percent).

9.4 Manual operation (hand held) of a durometer will cause variations in the results attained. Improved repeatability may be obtained by using a mass, securely affixed to the durometer and centered on the axis of the indentor. Recommended masses are 1 kg for Type A, B and O durometers, 5 kg for Type C, D and DO durometers, and 400 g for Type OO durometers. Further improvement may be achieved by the use of a durometer operating stand which controls the rate of descent of the durometer presser foot to the test specimen and incorporates the masses described above.

10. Report

10.1 *Instrument Calibration Report (Durometer or Operating Stand)*:

10.1.1 Date of calibration.

10.1.2 Date of last calibration.

10.1.3 Calibration due date (refer to Note 2).

10.1.4 Manufacturer, type, model, and serial number of the instrument, and a notation when a maximum indicator or timing device is present.

10.1.5 Values obtained (pre- and post calibration results), including a notation of the affect of a maximum indicator, if present. The method of reporting the calibrated value shall be by attaining the arithmetic mean of the determinations.

10.1.6 Ambient temperature.

10.1.7 Relative humidity.

10.1.8 Technician identification.

10.1.9 Applicable standards to which the instrument is calibrated.

10.1.10 Calibrating instrument information to include type, serial number, manufacturer, date of last calibration, calibration

TABLE 3 Type 1 Precision—Type A Durometer Method

Material	Average Level	Within Laboratories			Between Laboratories		
		Sr^A	r^B	$(r)^C$	SR^D	R^E	$(R)^F$
1	51.4	0.646	1.83	3.56	1.56	4.41	8.69
2	65.3	0.878	2.48	3.81	2.21	6.06	9.27
3	68.0	0.433	1.23	1.80	2.28	6.45	9.49
Pooled	61.6	0.677	1.92	3.11	2.018	5.72	9.28

[A] Sr = repeatability standard deviation, measurement units.
[B] r = repeatability = 2.83 × Sr, measurement units.
[C] (r) = repeatability, relative, (that is, in percent).
[D] SR = reproducibility standard deviation, measurement units.
[E] R = reproducibility = 2.83 × SR, measurement units.
[F] (R) = reproducibility, relative, (that is, in percent).

TABLE 4 Type 1 Precision—Type D Durometer Method

Material	Average Level	Within Laboratories			Between Laboratories		
		Sr^A	r^B	$(r)^C$	SR^D	R^E	$(R)^F$
1	42.6	0.316	0.894	2.10	2.82	7.98	18.7
2	54.5	0.791	2.24	4.11	3.54	10.0	18.4
3	82.3	1.01	2.86	3.47	3.54	10.0	12.2
Pooled	59.8	0.762	2.16	3.61	3.32	9.40	15.7

[A] Sr = repeatability standard deviation, measurement units.
[B] r = repeatability = 2.83 × Sr, measurement units.
[C] (r) = repeatability, relative, (that is, in percent).
[D] SR = reproducibility standard deviation, measurement units.
[E] R = reproducibility = 2.83 × SR, measurement units.
[F] (R) = reproducibility, relative, (that is, in percent).

due date (refer to Note 2) and a statement of traceability of standards used to NIST or other acceptable organization. See 1.5.

10.2 *Hardness Measurement Report*:

10.2.1 Date of test.

10.2.2 Relative humidity.

10.2.3 Ambient temperature.

10.2.4 Manufacturer, type and serial number of the durometer or operating stand, or both, including a notation when a maximum indicator or timing device is present, date of last calibration, and calibration due date (refer to Note 2).

NOTE 2—The calibration interval (calibration due date) for a durometer is to be determined by the user, based upon frequency of use, severity of conditions, environmental factors, and other variables.

Periodic checking of the operation and state of durometer calibration using commercially available rubber test blocks (refer to 7.8), specifically designed for this purpose, is recommended.

An instrument that has been exposed to severe shock, is visibly damaged, produces test determinations more than 2 points different from calibrated rubber test blocks or other reference standard, or is otherwise suspected of unreliability, should be removed from service and returned to a qualified calibration facility.

A calibration interval of one year is recommended for durometer test blocks and durometer instruments that are infrequently used, more often for others.

The calibration interval for instruments and peripheral devices employed in the calibration of durometers is to be determined by the calibration service provider. It is recommended that the protocols outlined in ISO/IEC 17025[6], as required by the manufacturer, and those to which the service is provided, be followed.

10.2.5 Means of testing, whether manual (hand held), Type 1 operating stand (specimen to indentor), Type 2 operating stand (indentor to specimen type), or Type 3 operating stand (electromechanical or hydraulically dampened).

10.2.6 Description of test specimen, including thickness, number of pieces plied if less than the thickness indicated in Section 6, including the vulcanization date.

10.2.7 Complete identification of material tested.

10.2.8 Hardness value obtained and method of calculation, either arithmetic mean or alternatively, the median.

10.2.9 Indentation hardness time interval at which determination was made. Readings may be reported in the form: M/60/1 where M is the type of durometer, 60 the reading, and 1 the time in seconds that the presser foot is in contact with the specimen or from an electronic timing device.

11. Precision and Bias

11.1 These precision and bias statements have been prepared in accordance with Practice D 4483. Refer to this Practice for terminology and other testing and statistical concepts.

11.2 The Type 1 precision for the Type M method was determined from an interlaboratory program with 21 materials of varying hardness, with six participating laboratories. Tests were conducted on two separate days in each laboratory for the Type M testing program. All materials were supplied from a single source, being those commonly supplied as reference materials with the instruments from the manufacturer.

11.3 The precision results in this precision and bias section give an estimate of the precision of this test method with the materials (rubbers) used in the particular interlaboratory program as described above. The precision parameters should not be used for acceptance or rejection testing, or both, of any group of materials without documentation that they are applicable to those particular materials and the specific testing protocols that include this test method.

11.4 The Type 1 precision for both Type A and D methods was determined from an interlaboratory program with 3 materials of varying hardness, with six participating laboratories. Tests were conducted on two separate days in each laboratory for both A and D testing programs. All materials were supplied from a single source.

11.5 A test result for hardness, for Types A, D, and M, was the median of five individual hardness readings on each day in each laboratory.

11.6 Table 2 shows the precision results for Type M method,[8] Table 3 shows the precision results for Type A method,[9] and Table 4 gives the precision results for Type D method.[9]

11.7 *Precision*—The precision of this test method may be expressed in the format of the following statements which use as appropriate value r, R, (r), or (R), that is, that value to be used in decisions about test results (obtained with the test method). The appropriate value is that value of r or R associated with a mean level in Table 1 closest to the mean level under consideration (at any given time, for any given material) in routine testing operations.

NOTE 3—A Type 1 precision statement for Types E, OOO, OOO-S, and R have not yet been made available.

[8] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR: D11-1091.

[9] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR: D11-1029.

11.7.1 *Repeatability*—The repeatability, *r*, of these test methods has been established as the appropriate value tabulated in Tables 2-4. Two single test results, obtained under normal test method procedures, that differ by more than this tabulated *r* (for any given level) must be considered as derived from different or non-identical sample populations.

11.7.2 *Reproducibility*—The reproducibility, *R*, of these test methods has been established as the appropriate value tabulated in Tables 2-4. Two single test results obtained in two different laboratories, under normal test method procedures, that differ by more than the tabulated *R* (for any given level) must be considered to have come from different or non-identical sample populations.

11.7.3 Repeatability and reproducibility are expressed as a percentage of the mean level, *(r)* and *(R)*, have equivalent application statements as above for *r* and *R*. For the *(r)* and *(R)* statements, the difference in the two single test results is expressed as a percentage of the arithmetic mean of the two test results.

11.8 *Bias*—In test method terminology, bias is the difference between an average test value and the reference (or true) test property value. Reference values do not exist for this test method since the value (of the test property) is exclusively defined by this test method. Bias, therefore cannot be determined.

12. Keywords

12.1 durometer; durometer hardness; hardness; indentation hardness; micro durometer hardness

APPENDIXES

(Nonmandatory Information)

X1. DUROMETER SELECTION GUIDE

X1.1 The durometer selection guide is designed to assist in the selection of the proper durometer type for various applications.

X1.2 It is generally recognized that durometer hardness determination below 20 and above 90 are unreliable. It is recommended that the next lower or higher type (scale) be used in these situations.

X1.3 It is also recommended that, whenever possible, an operating stand be employed in performing durometer hardness tests.

TABLE X1.1 Durometer Selection: Typical Uses

Type (Scale)	Typical Examples of Materials Tested	Durometer Hardness (Typical Uses)
A	Soft vulcanized rubber, natural rubber, nitriles, thermoplastic elastomers, flexible polyacrylics and thermosets, wax, felt, and leathers	20–90 A
B	Moderately hard rubber, thermoplastic elastomers, paper products, and fibrous materials	Above 90 A Below 20 D
C	Medium-hard rubber, thermoplastic elastomers, medium-hard plastics and thermoplastics	Above 90 B Below 20 D
D	Hard rubber, thermoplastic elastomers, harder plastics, and rigid thermoplastics	Above 90 A
DO	Moderately hard rubber, thermoplastic elastomers, and very dense textile windings	Above 90 C Below 20 D
M	Thin, irregularly shaped rubber, thermoplastic elastomer, and plastic specimens	20–85 A
O	Soft rubber, thermoplastic elastomers, very soft plastics and thermoplastics, medium-density textile windings	Below 20 DO
OO	Extremely soft rubber, thermoplastic elastomers, sponge, extremely soft plastics and thermoplastics, foams, low-density textile windings, human and animal tissue	Below 20 O
CF	Composite foam materials such as amusement ride safety cushions, vehicle seats, dashboards, headrests, armrests, and door panels	See Test Method F 1957

X2. RELATED TEST METHODS

C 367 Test Methods for Strength Properties of Prefabricated Architectural Acoustical Tile or Lay-In Ceiling Panels[10]

C 473 Test Methods for Physical Testing of Gypsum Panel Products[11]

C 581 Practice for Determining Chemical Resistance of Thermosetting Resins Used in Glass-Fiber-Reinforced Structures Intended for Liquid Service[12]

C 661 Test Method for Indentation Hardness of Elastomeric-Type Sealants by Means of a Durometer[13]

C 836 Specification for High Solids Content, Cold Liquid-Applied Elastomeric Waterproofing Membrane for Use with Separate Wearing Course[13]

D 461 Test Methods for Felt[14]

D 531 Test Method for Rubber Property—Pusey and Jones Indentation[4]

D 619 Test Methods for Vulcanized Fibre Used for Electrical Insulation[2]

D 1037 Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials[15]

D 1054 Test Method for Rubber Property—Resilience Using a Rebound Pendulum[4]

D 1414 Test Methods for Rubber O-Rings[16]

D 1474 Test Methods for Indentation Hardness of Organic Coatings[17]

D 2134 Test Method for Determining the Hardness of Organic Coatings with a Sward-Type Hardness Rocker[17]

D 2287 Specification for Nonrigid Vinyl Chloride Polymer and Copolymer Molding and Extrusion Compounds[3]

D 2583 Test Method for Indentation Hardness of Rigid Plastics by Means of a Barcol Impressor[18]

D 2632 Test Method for Rubber Property—Resilience by Vertical Rebound[4]

D 4289 Test Method for Elastomer Compatibility of Lubricating Greases and Fluids[19]

D 5672 Test Method for Testing Flexible Cellular Materials–Measurement of Indentation Force Deflection Using a 25-mm (1-in.) Deflection Technique[20]

D 6546 Test Methods for and Suggested Limits for Determining Compatibility of Elastomer Seals for Industrial Hydraulic Fluid Applications[21]

F 1151 Test Method for Determining Variations in Hardness of Film Ribbon Pancakes[22]

NOTE X2.1—The hardness testing of other nonmetallic materials may be under the jurisdiction of one or more ASTM committees; the respective committee should be contacted for specific information.

[10] *Annual Book of ASTM Standards*, Vol 04.06.
[11] *Annual Book of ASTM Standards*, Vol 04.01.
[12] *Annual Book of ASTM Standards*, Vol 08.04.
[13] *Annual Book of ASTM Standards*, Vol 04.07.
[14] *Annual Book of ASTM Standards*, Vol 07.01.
[15] *Annual Book of ASTM Standards*, Vol 04.10.
[16] *Annual Book of ASTM Standards*, Vol 09.02.
[17] *Annual Book of ASTM Standards*, Vol 06.01.
[18] *Annual Book of ASTM Standards*, Vol 08.02.
[19] *Annual Book of ASTM Standards*, Vol 05.02.
[20] *Annual Book of ASTM Standards*, Vol 08.03.
[21] *Annual Book of ASTM Standards*, Vol 05.04.
[22] *Annual Book of ASTM Standards*, Vol 15.09.

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JAPANESE INDUSTRIAL STANDARD

JIS K 6253 : 1997

Hardness testing methods for rubber, vulcanized or thermoplastic

Introduction This Japanese Industrial Standard has been prepared on the basis of the 3rd edition of **ISO 48**, *Rubber, vulcanized or thermoplastic—Determination of hardness (hardness between 10 IRHD and 100 IRHD)* published in 1994, and the 1st edition of **ISO 7619**, *Rubber—Determination of indentation hardness by means of pocket hardness meters* published in 1986, without any modification in technical contents. However, "Type E of spring type (durometer hardness)" which is not specified in the corresponding International Standards are added in this Standard.

1 Scope This Japanese Industrial Standard specifies the testing methods to measure hardness of vulcanized rubber and thermoplastic rubber (hereafter referred to as "vulcanized rubber").

Remarks 1 The standards cited in this Standard are listed as follows.

JIS K 6200 *Glossary of terms used in rubber industry*

JIS K 6250 *General rules of physical testing methods for rubber, vulcanized or thermoplastic*

JIS Z 8401 *Rules for rounding off of numerical values*

2 The International Standards corresponding to this Standard are listed as follows.

ISO 48 : 1994 *Rubber, vulcanized or thermoplastic—Determination of hardness (hardness between 10 IRHD and 100 IRHD)*

ISO 7619 : 1986 *Rubber—Determination of indentation hardness by means of pocket hardness meters*

3 The units and numerical values given in { } in this Standard are based on traditional units, and are appended for informative reference.

2 Definitions For the purposes of this Standard, the definitions given in **JIS K 6200** and **JIS K 6250**, and the following definitions apply.

(1) **international rubber hardness degree** Hardness which can be obtained through conversion into international rubber hardness degree (IRHD)[1] using the depth of indentation by a plunger when the plunger, with a ball-type lower end, is vertically impressed on the surface of a test piece with specified indenting force.

A hardness scale is chosen so that "0" represents the hardness of material having a Young's modulus of zero and "100" represents the hardness of a material of infinite Young's modulus, and the following conditions are fulfilled over most of normal range of hardness.

(a) One international rubber hardness degree always represents approximately the same proportionate difference in the Young's modulus.

(b) For highly elastic rubber, the scales of international rubber hardness degree and that of type A durometer are comparable.

Note (1) IRHD International Rubber Hardness Degree

(2) **durometer hardness** The hardness given by the testing apparatus (durometer) which reads the indentation depth made by a specifically shaped indentor when it is impressed on the surface of a test piece via a spring.

(3) **IRHD pocket hardness** The hardness given by a portable pocket testing apparatus (IRHD pocket hardness meter) by which international rubber hardness degree can be conveniently obtained owing to reading the indented depth made by an indentor, with a ball-type lower end, when it impressed on the surface of a test piece via a spring.

(4) **standard hardness** The hardness obtained using the specified procedures on test pieces whose shape and dimensions satisfy the specifications, when carrying out each test.

(5) **apparent hardness** The hardness obtained either using other procedures than the specified, or on the test piece whose shape and dimensions do not satisfy the specification, when carrying out each test.

3 Type of test

3.1 Outline of hardness test There are many types of testing methods for hardness test depending on the principle of hardness measurement, kind of testing apparatus and so on, and they are classified into standard hardness and apparent hardness by shape or dimensions of a test piece. The outline of classifying is shown in Table 1.

Table 1 Outline of hardness tests

Principle of measurement	Range of hardness measurement	Type of testing apparatus	Testing method	Test condition for standard hardness: Shape	Thickness mm	Minimum distance from the edge of sample mm
Constant-force type (international rubber hardness degree)	For high hardness (85 to 100 IRHD)	Normal size international rubber hardness meter	H method	Both upper and lower surfaces are smooth and parallel each other.	8.0 min.	9.0
					10.0 max.	10.0
	For normal hardness (30 to 95 IRHD)	Normal size international rubber hardness meter	N method		8.0 min.	9.0
					10.0 max.	10.0
		Microsize international rubber hardness meter	M method		1.5 min.	2.0
					2.5 max.	
	For low hardness (10 to 35 IRHD)	Normal size international rubber hardness meter	L method		10.0 min.	10.0
					15.0 max.	11.5
Spring type (durometer hardness)	For high hardness (A90 or more)	Type D durometer			6.0 or more	12.0
	For normal hardness (A10 to 90)	Type A durometer			6.0 or more	12.0
	For low hardness (A20 or less)	Type E durometer			10.0 or more	12.0
Spring type (IRHD pocket hardness)	For normal hardness (30 to 95 IRHD)	IRHD pocket hardness meter	P method		6.0 or more	12.0

3.2 Type of tests The type of hardness tests for vulcanized rubber shall be classified as follows.

(1) **International rubber hardness test**

(a) H method (normal size test for high hardness)

(b) N method (normal size test for normal hardness)

(c) M method (microsize test for normal hardness)

(d) L method (normal size test for low hardness)

(2) **Durometer hardness test**

(a) Type D (test for high hardness)

(b) Type A (test for normal hardness)

(c) Type E (test for low hardness)

(3) **IRHD pocket hardness test**

(a) P method (for normal hardness)

4 International rubber hardness test

4.1 Purpose This test shall be carried out to measure the international rubber hardness degree of vulcanized rubber.

4.2 Range of measurement The measuring range of this test is decided according to the thickness and hardness of a test piece for every testing method. The measuring range of each testing method is as follows.

(1) **H method** Formal measuring range shall be for the test piece measuring 8.0 mm to 10.0 mm in thickness and with hardness of 85 IRHD to 100 IRHD. It is permissible to test the one with 4.0 mm or more thickness and with hardness of 85 IRHD to 100 IRHD.

(2) **N method** Formal measuring range shall be for the test piece measuring 8.0 mm to 10.0 mm in thickness and with hardness of 35 IRHD to 85 IRHD. It is permissible to test the one with 4.0 mm or more thickness and with hardness of 30 IRHD to 95 IRHD(2).

(3) **M method** Formal measuring range shall be for the test piece measuring 1.5 mm to 2.5 mm in thickness and with hardness of 35 IRHD to 85 IRHD. It is permissible to test the one with 1.0 mm to 4.0 mm thickness and with hardness of 30 IRHD to 95 IRHD(3).

(4) **L method** Formal measuring range shall be for the test piece measuring 10.0 mm to 15.0 mm in thickness and with hardness of 10 IRHD to 35 IRHD. It is permissible to test the one with 6.0 mm or more thickness and with hardness of 10 IRHD to 35 IRHD.

Notes (2) The hardness values in 85 IRHD to 95 IRHD and 30 IRHD to 35 IRHD obtained by N method do not exactly coincide with the values by H method and L method, but the discrepancy does not come into technical problem, generally speaking.

(3) The testing apparatus for M method is the one prepared by miniaturizing the testing apparatus for N method by about one-sixth to measure the test piece with thin thickness, therefore the depth of plunger indentation by M method is just one-sixth that by N method. The results given by M method are not always coincident with the results given by N method because of the surface effect of rubber or slight roughness of the surface.

.3 Testing apparatus

.3.1 Outline of testing apparatus The testing apparatus is composed of a holding ase for test piece by which a test piece is kept, an annular pressure foot by which the ırface of a test piece is pressed, a plunger, with a ball-type lower end, set at the cenır of hole of pressure foot, a device for loading which gives an indenting force on a lunger to make an indentation on a test piece, a measuring device to measure depth : an indentation impressed on a test piece, and a vibrating device to lessen friction. he dimensions of main parts and the specification of force are shown in Table 2.

A thermostat may be provided for measuring a test temperature other than stanard condition of laboratory.

Table 2 Main dimensions and forces of testing apparatus

ype f tests	Diameter of ball of plunger end mm	Face of pressure foot			Force applying at ball of plunger end		
		Diameter mm	Diameter of hole mm	Force exerted on face of pressure foot	Contact force	Indenting force	Total
ı ethod	1.00±0.01	20±1	6±1				
f ethod	2.50±0.01	20±1	6±1	8.3±1.5 N {846±153 gf}	0.30±0.02 N {30.6±2.0 gf}	5.40±0.01 N {550.6±1.0 gf}	5.70±0.03 N {581.2±3.1 gf}
ethod	5.00±0.01	22±1	10±1				
I ethod	0.395±0.005	3.35±0.15	1.00±0.15	235±30 mN (4) {24.0±3.1 gf}	8.3±0.5 mN {0.85±0.05 gf}	145±0.5 mN {14.79±0.05 gf}	153±1 mN {15.60±0.10 gf}

Note (4) When in M method a pressure adjusting spring installed at the bottom of a test-piece holding base makes pressure adjustment, the pressure adjusting spring must be controlled to be (380±30) mN {(38.7±3.1) gf} because an indenting force 145 mN {14.8 gf} is added during measurement.

3.2 Face of pressure foot An annular pressure foot makes rectangular to a unger. The diameter of face of pressure foot and the diameter of the hole for a plunger e as shown in Table 2. When the force exerted on the face of pressure foot is just as own in Table 2, the pressure impressed on the surface of test piece becomes (30±5) kPa).306±0.051) kgf/cm²}(5). In order to measure the relative displacement between the ce of pressure foot (upper surface of test piece) and the plunger, the face of pressure ot shall be firmly united with the measuring device of the depth of indentation.

Note (5) Some combination of all tolerances shown in Table 2 does not always give nice coincidence with the description of pressure (30±5) kPa {(0.306±0.051) kgf/cm²}.

4.3.3 Plunger The plunger shall be vertical, and its lower end has spherical shape whose diameter shall be as shown in Table 2(6). The lower end ball of a plunger shall be kept a little upper than the face of pressure foot before contact force is applied.

Note (6) The material of end ball shall be abrasion resistant and corrosion resistant.

When an end ball is connected with the body of plunger, the connected part must not be larger than diameter of the ball.

4.3.4 Loading device Loading device shall accurately apply the contact force(7) and indenting force(8) specified in Table 2 to the end ball of a plunger.

Notes (7) Contact force means the force causing the end ball of a plunger to contact with surface of a test piece.

(8) Indenting force means the force to impress the end ball of a plunger into test piece after making contact.

4.3.5 Measuring device of indented depth The measuring device for indented depth shall be capable of measuring indented depth of a plunger when indenting force is applied to a plunger, by which the indented depth or IRHD shall be directly read(9). The conversion from indented depth to IRHD can be done through Table 3, Table 4 and Table 5(10).

Notes (9) For the measuring device of indented depth, any of mechanical, optical, or electrical, is serviceable.

(10) Table 3 is for the conversion of H method, and Table 4 for N method. In case of M method, convert after making the indented depth shown in Table 4 one-sixth. Table 5 is the conversion table for L method.

4.3.6 Vibrating device To overcome minute friction, it is preferable to install a vibrating device like an electric buzzer by which a testing apparatus is suitably vibrated. It can be eliminated if friction is completely removed.

4.3.7 Thermostat The thermostat is needed when the test temperature other than standard condition of laboratory is employed for measuring hardness. The thermostat must keep the specified temperature in the tolerance of ±2 °C. The annular foot with pressure face at lower end and a plunger shall penetrate through the upper part of the thermostat.

The part through which the plunger penetrates shall be made of the material with small thermal conductivity. The sensor for temperature measurement shall be installed at holding place of test piece or its vicinity, in the thermostat.

Table 3 Conversion table from indented depth (D) of a plunger to international rubber hardness degree (IRHD) (H method)

D mm	International rubber hardness degree IRHD	D mm	International rubber hardness degree IRHD	D mm	International rubber hardness degree IRHD
0.00	100.0	0.15	97.3	0.30	91.1
0.01	100.0	0.16	97.0	0.31	90.7
0.02	100.0	0.17	96.6	0.32	90.2
0.03	99.9	0.18	96.2	0.33	89.7
0.04	99.9	0.19	95.8	0.34	89.3
0.05	99.8	0.20	95.4	0.35	88.8
0.06	99.6	0.21	95.0	0.36	88.4
0.07	99.5	0.22	94.6	0.37	87.9
0.08	99.3	0.23	94.2	0.38	87.5
0.09	99.1	0.24	93.8	0.39	87.0
0.10	98.8	0.25	93.4	0.40	86.6
0.11	98.6	0.26	92.9	0.41	86.1
0.12	98.3	0.27	92.5	0.42	85.7
0.13	98.0	0.28	92.0	0.43	85.3
0.14	97.6	0.29	91.6	0.44	84.8

Table 4 Conversion table from indented depth (*D*) of a plunger to international rubber hardness degree (IRHD) (N method)

D mm	International rubber hardness degree IRHD	*D* mm	International rubber hardness degree IRHD	*D* mm	International rubber hardness degree IRHD	*D* mm	International rubber hardness degree IRHD
0.00	100.0	0.45	73.9	0.90	52.3	1.35	38.9
0.01	100.0	0.46	73.3	0.91	52.0	1.36	38.7
0.02	99.9	0.47	72.7	0.92	51.6	1.37	38.4
0.03	99.8	0.48	72.2	0.93	51.2	1.38	38.2
0.04	99.6	0.49	71.6	0.94	50.9	1.39	38.0
0.05	99.3	0.50	71.0	0.95	50.5	1.40	37.8
0.06	99.0	0.51	70.4	0.96	50.2	1.41	37.5
0.07	98.6	0.52	69.8	0.97	49.8	1.42	37.3
0.08	98.1	0.53	69.3	0.98	49.5	1.43	37.1
0.09	97.7	0.54	68.7	0.99	49.1	1.44	36.9
0.10	97.1	0.55	68.2	1.00	48.8	1.45	36.7
0.11	96.5	0.56	67.6	1.01	48.5	1.46	36.5
0.12	95.9	0.57	67.1	1.02	48.1	1.47	36.2
0.13	95.3	0.58	66.6	1.03	47.8	1.48	36.0
0.14	94.7	0.59	66.0	1.04	47.5	1.49	35.8
0.15	94.0	0.60	65.5	1.05	47.1	1.50	35.6
0.16	93.4	0.61	65.0	1.06	46.8	1.51	35.4
0.17	92.7	0.62	64.5	1.07	46.5	1.52	35.2
0.18	92.0	0.63	64.0	1.08	46.2	1.53	35.0
0.19	91.3	0.64	63.5	1.09	45.9	1.54	34.8
0.20	90.6	0.65	63.0	1.10	45.6	1.55	34.6
0.21	89.8	0.66	62.5	1.11	45.3	1.56	34.4
0.22	89.2	0.67	62.0	1.12	45.0	1.57	34.2
0.23	88.5	0.68	61.5	1.13	44.7	1.58	34.0
0.24	87.8	0.69	61.1	1.14	44.4	1.59	33.8
0.25	87.1	0.70	60.6	1.15	44.1	1.60	33.6
0.26	86.4	0.71	60.1	1.16	43.8	1.61	33.4
0.27	85.7	0.72	59.7	1.17	43.5	1.62	33.2
0.28	85.0	0.73	59.2	1.18	43.3	1.63	33.0
0.29	84.3	0.74	58.8	1.19	43.0	1.64	32.8
0.30	83.6	0.75	58.3	1.20	42.7	1.65	32.6
0.31	82.9	0.76	57.9	1.21	42.5	1.66	32.4
0.32	82.2	0.77	57.5	1.22	42.2	1.67	32.3
0.33	81.5	0.78	57.0	1.23	41.9	1.68	32.1
0.34	80.9	0.79	56.6	1.24	41.7	1.69	31.9
0.35	80.2	0.80	56.2	1.25	41.4	1.70	31.7
0.36	79.5	0.81	55.8	1.26	41.1	1.71	31.6
0.37	78.9	0.82	55.4	1.27	40.9	1.72	31.4
0.38	78.2	0.83	55.0	1.28	40.6	1.73	31.2
0.39	77.6	0.84	54.6	1.29	40.4	1.74	31.1
0.40	77.0	0.85	54.2	1.30	40.1	1.75	30.9
0.41	76.4	0.86	53.8	1.31	39.9	1.76	30.7
0.42	75.8	0.87	53.4	1.32	39.6	1.77	30.5
0.43	75.2	0.88	53.0	1.33	39.4	1.78	30.4
0.44	74.5	0.89	52.7	1.34	39.1	1.79	30.2
						1.80	30.0

Table 5 Conversion table from indented depth (*D*) of a plunger to international rubber hardness degree (IRHD) (L method)

D mm	International rubber hardness degree IRHD	*D* mm	International rubber hardness degree IRHD	*D* mm	International rubber hardness degree IRHD
1.10	34.9	1.80	21.3	2.50	14.1
1.12	34.4	1.82	21.1	2.52	14.0
1.14	33.9	1.84	20.8	2.54	13.8
1.16	33.4	1.86	20.6	2.56	13.7
1.18	32.9	1.88	20.3	2.58	13.5
1.20	32.4	1.90	20.1	2.60	13.4
1.22	31.9	1.92	19.8	2.62	13.3
1.24	31.4	1.94	19.6	2.64	13.1
1.26	30.9	1.96	19.4	2.66	13.0
1.28	30.4	1.98	19.2	2.68	12.8
1.30	30.0	2.00	18.9	2.70	12.7
1.32	29.6	2.02	18.7	2.72	12.6
1.34	29.2	2.04	18.5	2.74	12.5
1.36	28.8	2.06	18.3	2.76	12.3
1.38	28.4	2.08	18.0	2.78	12.2
1.40	28.0	2.10	17.8	2.80	12.1
1.42	27.6	2.12	17.6	2.82	12.0
1.44	27.2	2.14	17.4	2.84	11.8
1.46	26.8	2.16	17.2	2.86	11.7
1.48	26.4	2.18	17.0	2.88	11.6
1.50	26.1	2.20	16.8	2.90	11.5
1.52	25.7	2.22	16.6	2.92	11.4
1.54	25.4	2.24	16.4	2.94	11.3
1.56	25.0	2.26	16.2	2.96	11.2
1.58	24.7	2.28	16.0	2.98	11.1
1.60	24.4	2.30	15.8	3.00	11.0
1.62	24.1	2.32	15.6	3.02	10.9
1.64	23.8	2.34	15.4	3.04	10.8
1.66	23.5	2.36	15.3	3.06	10.6
1.68	23.1	2.38	15.1	3.08	10.5
1.70	22.8	2.40	14.9	3.10	10.4
1.72	22.5	2.42	14.8	3.12	10.3
1.74	22.2	2.44	14.6	3.14	10.2
1.76	21.9	2.46	14.4	3.16	10.1
1.78	21.6	2.48	14.3	3.18	9.9

4.4 Test piece

4.4.1 Shape of test pieces Both surfaces of a test piece shall be smoothly flat and parallel each other(11). This test has been supposed to compare the test pieces having the same thickness.

Note (11) The surface such as unsmoothed, curved, or rough, does not give satisfactory results. For specially formed surface, however, such as rubber roll, this method can be applied.

The international rubber hardness testing method for curved test piece is shown in Informative reference.

4.4.2 Thickness

(1) **H method and N method** The standard thickness of a test piece is 8.0 mm to 10.0 mm, but to get necessary thickness, it is permissible to pile smooth and parallel test pieces. Provided that the thickness of test pieces before piling shall be 2 mm or more, and 3 or more test pieces cannot be piled up. Even when nonstandard test piece other than above(12) is to be adopted, the thickness of the test piece must be 4.0 mm or more.

(2) **L method** The standard thickness of a test piece is 10.0 mm to 15.0 mm, but to get necessary thickness, it is permissible to pile smooth and parallel test pieces. Provided that the thickness of test pieces before piling shall be 2 mm or more, and 3 or more test pieces cannot be piled up. Even when nonstandard test piece other than above(12) is to be adopted, the thickness of the test piece must be 6.0 mm or more.

(3) **M method** The standard thickness of a test piece is (2.0 ±0.5) mm. Even when nonstandard test piece other than above(12) is to be adopted, the thickness of the test piece must be 1.0 mm or more.

Note (12) The measured value resulted from nonstandard test piece, is not generally coincident with the measured value by standard test piece.

4.4.3 Lateral dimensions

(1) **H method, N method, and L method** The lateral dimension of a test piece shall be large enough to measure at the point which is apart from edge of the test piece by at least the distance shown in Table 6.

Table 6 Minimum distance of point for hardness measurement (point of end ball of plunger) from test-piece edge

Unit: mm

Thickness of a test piece	Minimum distance of point for hardness measurement from test-piece edge
4.0	7.0
6.0	8.0
8.0	9.0
10.0	10.0
15.0	11.5
25.0	13.0

(2) **M method** The lateral dimension of a test piece shall be large enough to measure at the point which is apart from edge of the test piece by at least 2.0 mm. When the test piece, with the thickness of 4.0 mm or more, which is not eligible for N method because of small lateral dimension or of not having large smooth area, is to be tested by M method, carry out test at the point apart from edge of the test piece as far as possible.

4.4.4 Sampling and preparation of test pieces The sampling and preparation of test pieces shall principally follow **6.5** of **JIS K 6250**.

4.4.5 Selection of test pieces The test pieces which contain alien matters, bubbles, or flaws shall not be used for tests.

4.5 Testing method

4.5.1 Testing conditions Testing conditions shall be as follows.

(1) The standard conditions of a laboratory shall follow **6.1** of **JIS K 6250**.

(2) Storing of sample and test pieces shall follow **6.2** of **JIS K 6250**.

(3) The standard conditions of test pieces shall follow **6.3** of **JIS K 6250**.

4.5.2 Procedures Sprinkle slightly talc on upper and back surfaces of a test piece to lessen friction between the end ball of a plunger and surface of a test piece. Place the test piece on the holding base of a test piece. Make the face of pressure foot touch with the surface of the test piece.

(1) When the scale is graduated with IRHD, apply contact force to the plunger for 5 s, and adjust the scale to be 100. Then, apply indenting force for 30 s, and read directly hardness by IRHD.

(2) When the scale is graduated with indented depth, apply contact force to the plunger for 5 s, and read the scale. Then, apply indenting force for 30 s, and read the scale. Calculate the difference between indentation by contact force and that by indenting force, and make this the indented depth *D*. Convert the value of *D* into IRHD making use of Table 3, Table 4, and Table 5.

While applying force, the slight vibration may be applied on the testing apparatus by a vibrating device to overcome the friction. Carry out measurements at 3 or 5 new points on a test piece at every measurement.

4.6 Arrangement of test results Round off the median of 3 or 5 measurements to whole number according to **JIS Z 8401**, and mark the sign IRHD after it. In case of standard hardness, after it mark "/" together with letter "S", and then mark "/" with sign as H, N, M, or L, which means testing method. In case of apparent hardness, after sign of IRHD mark "/" together with sign as H, N, M, or L, which means testing method.

Example 1 50 IRHD/S/N: means that standard test piece is measured by N method of international rubber hardness test, and standard hardness is 50 IRHD.

Example 2 50 IRHD/M: means that nonstandard test piece is measured by M method of international rubber hardness test, and apparent hardness is 50 IRHD.

4.7 Record On test result, the following items shall be recorded.

(1) Test result

(2) Shape and dimensions of test piece (whether standard test piece or nonstandard one; in case of nonstandard, whether curved surface or not; and in case of piled one, the number of piled pieces and its thickness)

(3) Sampling and preparation methods of test pieces

(4) Test temperature

(5) Other items specially needed

5 Durometer hardness test

5.1 Purpose This test shall be carried out to measure durometer hardness of vulcanized rubber.

5.2 Range of measurement The measuring range of this test is decided according to the hardness of test piece at every testing method. The measuring range of each testing method is as follows.

(1) **Type D durometer** The measuring range of type D durometer hardness is the range over A90 by type A durometer. When less than D20, measure by type A durometer.

(2) **Type A durometer** The measuring range of type A durometer hardness is from A10 to A90, and when over A90, measure by type D durometer. When less than A20, measure by type E durometer.

(3) **Type E durometer** The measuring range of type E durometer hardness is the range of less than A20 by type A durometer.

5.3 Testing apparatus

5.3.1 Outline of testing apparatus The testing apparatus is composed of the face of pressure foot by which the surface of a test piece is pressed, indentor which protrudes from a central hole of face of pressure foot by action of a spring, and the graduation which indicates the distance (indenting depth) of indentor rejected by rubber cushion and which represents hardness itself.

5.3.2 Face of pressure foot The face of pressure foot is perpendicular to the indentor, and its center has a hole for the indentor. The diameter of the hole, in case of type D and type A durometer, is $3.0^{+0.2}_{-0.5}$ mm, and in case of type E durometer, (5.4±0.2) mm.

On the face of pressure foot, the distance from any place of its outer edge to the center of an indentor shall be, in case of type D and type A durometer, 6 mm or more, and in case of type E durometer, 7 mm or more.

5.3.3 Indentor The material of indentor shall be abrasion resistant and corrosion resistant, and it shall be accurately fixed at center of the hole of face of pressure foot. Its shape and dimensions are indicated in Fig. 1 for type D durometer, in Fig. 2 for type A durometer, and in Fig. 3 for type E durometer.

Unit: mm

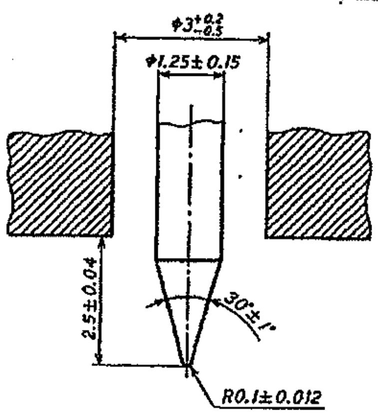


Fig. 1 Indentor for type D durometer

Unit: mm

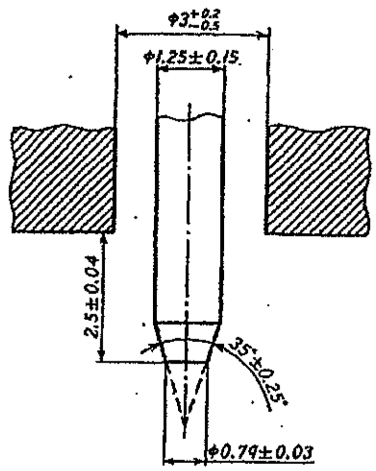


Fig. 2 Indentor for type A durometer

Unit: mm

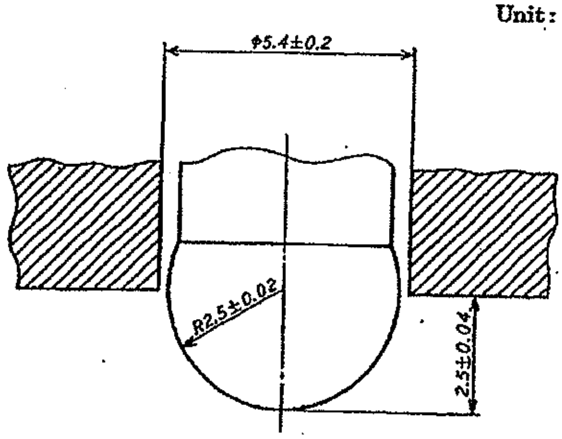


Fig. 3 Indentor for type E durometer

5.3.4 Scale When the scale indicates 0 (full protrusion), the point of the indentor shall protrude by (2.50±0.04) mm beyond the face of the pressure foot.

When the scale indicates 100 (nil protrusion), the face of the pressure foot is in firm contact with a flat piece of glass, i.e. the point of the indentor shall be positioned on the same plane with the face of the pressure foot. The scale shall be graduated with equal intervals in the range between 0 to 100.

5.3.5 Spring There must be the following relation between the force of spring and the scale, that is, the durometer hardness.

(1) Type D durometer

$$W_D = 444.5H_D \{w_D = 45.33H_D\}$$

where, W_D : force of spring of type D durometer (mN)

w_D : force of spring of type D durometer {gf}

H_D : hardness of type D durometer

(2) Type A and type E durometer

$$W_A = 550 + 75H_A \{w_A = 56.1 + 7.65H_A\}$$

where, W_A : force of spring of type A or type E durometer (mN)

w_A : force of spring of type A or type E durometer {gf}

H_A : hardness of type A or type E durometer

The tolerance of force shall be, in case of type D durometer, ±440 mN {±44.9 gf}, and in case of type A and type E durometer, ±80 mN {±8.16 gf}.

5.3.6 Calibration of spring Hold vertically the end point of indentor of a durometer on a balance not to give any interference between the balance and face of pressure foot, via a spacer (see Fig. 4). The cylindrical spacer with 2.5 mm height, in case of type D and type A durometer, measuring 1.25 mm in diameter, and in case of type E durometer, measuring 3 mm in diameter, has a wineglass shape where an indentor is to touch, in order to smoothly receive the end point of the indentor. Place a tare on the balance against the weight of the spacer. Place counterweight to get suitable scale, and confirm that the force (mN) shown here stays within the tolerance of specified force in 5.3.5. Carry out the above calibration using suitable scale interval.

The calibration of spring of a durometer may be done with an electrobalance other than chemical balance shown in Fig. 4. In this case, the measuring sensitivity of the force at end point of an indentor shall be, in case of type D durometer, 44 mN {4.5 gf} or less, and in case of type A and type E durometer, 8 mN {0.82 gf} or less.

The following method is permissible; place upside down the durometer, and directly apply the load on its indentor by counterweight. Provided that the correction about the mass of parts inside of the durometer shall be considered to prevent the discrepancy between this method and the method by Fig. 4. In this case, the accuracy on the mass of counterweight shall be ±4.5 g or less in case of type D durometer and ±0.82 g or less in case of type A and type E durometer.

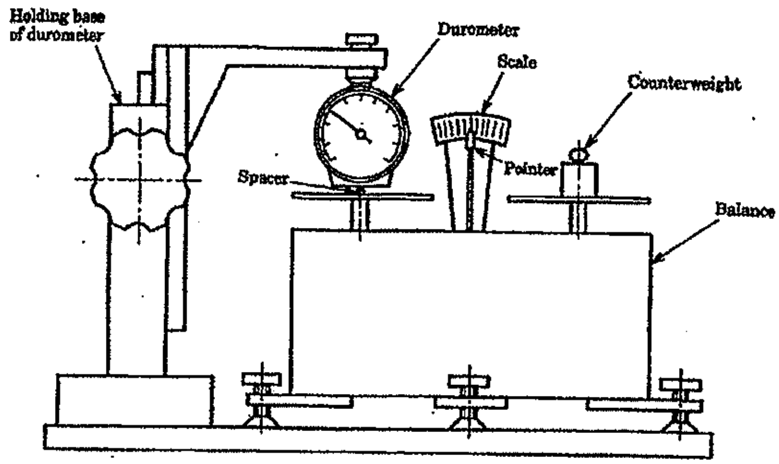


Fig. 4 Example of calibration apparatus of spring

5.4 Test piece

5.4.1 Shape and dimensions of test pieces The thickness of a test piece for type D and type A durometer is 6 mm or more. When it is less than 6 mm, pile them to make 6 mm or more for measurement. The thickness of a test piece for type E durometer is 10 mm or more, and in case of less than 10 mm, pile them to make 10 mm or more. The number of test pieces to pile shall be at most 3, and each of them shall have 2 mm or more thickness. The test result brought by piled up test piece doesn't generally coincide with the result by solid test piece(13). The lateral size of test piece shall be large enough to measure at the point where the end point of an indentor is apart 12 mm or more from the edge of the test piece.

Furthermore, the test piece shall have smooth surface spacious enough to make close contact with face of pressure foot of a durometer(14).

Notes (13) To make comparison, it is necessary to use the test piece which has the same number for piling and the same thickness.

(14) The surface such as unsmoothed, curved, or rough, does not give satisfactory results. For specially formed surface, however, such as rubber roll, this method can be applied. In this case, the applicable limit of the durometer shall be definitely confirmed.

5.4.2 Sampling and preparation of test pieces The sampling and preparation of test pieces shall follow **6.5** of **JIS K 6250**.

5.4.3 Selection of test pieces The test pieces which contain alien matters, bubbles, or flaws shall not be used for test.

5.5 Testing method

5.5.1 Testing conditions Testing conditions shall be as follows.

(1) The standard conditions of a laboratory shall follow **6.1** of **JIS K 6250**.

(2) Storing of sample and test pieces shall follow **6.2** of **JIS K 6250**.

(3) The standard conditions of test pieces shall follow **6.3** of **JIS K 6250**.

5.5.2 Procedures Place a test piece on a rigid, hard, and flat surface. Set a durometer so as to make an indentor rectangular to the target surface of a test piece. Contact closely as swiftly as possible the face of pressure foot with the target surface of the test piece without giving a impact, and read the scale within 1 s, to find the hardness of the test piece(15). But the agreement between the parties concerned with delivery may permit to read when a definite time passed after close contacting between them. The end point of the indentor of a durometer must be apart 12 mm or more from the edge of the test piece. Unless otherwise specified, the duration from close contacting to the finish of reading shall be recorded. The measuring points shall be 5, which are apart at least 6 mm each other, and carry out measurements 5 times on these points. When hardness shown by type A durometer is over A90, employ a type D durometer. When the hardness shown by type D durometer is less than D20, employ a type A durometer. If the hardness by type A durometer is less than A10, result is inaccurate, so don't record it.

When the hardness by a type A durometer is less A20, measure it with a type E durometer.

Note (15) In order to get a good repeatability, the holding base for durometer may be used by which the durometer is vertically kept and target surface and indentor get right angle each other before measurement. In this case, it is recommended that the mass imposed on the pressing surface is 5.0 kg for type D durometer, and 1.0 kg for both type A and type E durometer.

5.6 Arrangement of test results Round off the median of 5 measurements to whole number according to **JIS Z 8401**, and mark sign D in case of type D durometer, sign A in case of type A durometer, and sign E in case of type E durometer, just before the rounded value. When the value was read when definite time passed after close contacting, mark sign "/" and then record the duration (s). When it is standard hardness, the above is followed by "/" and then by sign S.

Example 1 D85/15/S: means that standard test piece is measured by type D durometer hardness test, and the reading on standard hardness is 85 when 15 s passed after close contacting of face of pressure foot.

Example 2 A45/S: means that standard test piece is measured by type A durometer hardness test, and the reading on standard hardness is 45 within 1 s after close contacting of face of pressure foot.

Example 3 A45/15: means that nonstandard test piece is measured by type A durometer hardness test, and the reading on apparent hardness is 45 when 15 s passed after close contacting of face of pressure foot.

Example 4 E60: means that nonstandard test piece is measured by type E durometer hardness test, and the reading on apparent hardness is 60 within 1 s after close contacting of face of pressure foot.

5.7 Record On test result, the following items shall be recorded.

(1) Test result

(2) Shape and dimensions of test piece (whether standard test piece or nonstandard test piece; in case of piled up test piece, the number of piled pieces, and its thickness)

(3) Sampling and preparation methods of test pieces

(4) Other items specially needed

6 IRHD pocket hardness test

6.1 Purpose This test shall be carried out to measure the international rubber hardness degree of vulcanized rubber by IRHD pocket hardness meter, and abbreviated P method.

6.2 Testing apparatus

6.2.1 Outline of testing apparatus The testing apparatus is composed of a face of pressure foot to press the surface of a test piece, indentor which protrudes from a central hole of face of pressure foot by action of a spring, and a mechanism indicating the protruded length of the indentor.

6.2.2 Face of pressure foot The face of pressure foot, measuring (20 ±2.5) mm sided square, has a hole with 2.0 mm to 3.0 mm diameter at its center.

6.2.3 Indentor The end of the indentor shall make a hemisphere with 1.55 mm to 1.60 mm diameter.

6.2.4 Indicating mechanism The indicating mechanism shows the protruded length of an indentor from face of pressure foot, and it shall have been calibrated to read directly the international rubber hardness degree by IRHD. When the longest protruded length of 1.65 mm is given, it must show 28 IRHD, and when the face of pressure foot is let contact with a flat glass, that is, no protruded, it must show 100 IRHD.

6.2.5 Spring Spring can apply constant force of (2.65 ±0.15) N {(270.3 ±15.3) gf} to an indentor in the range from 28 IRHD to 100 IRHD.

6.2.6 Calibration of hardness meter IRHD pocket hardness meter shall be calibrated and adjusted using a standard rubber block whose international rubber hardness degree has been known. Only when the standard rubber block cannot be used, it is preferably calibrated with mechanical method.

Press the IRHD pocket hardness meter on a flat glass plate, and adjust the scale to get 100 IRHD. Making use of a set of standard rubber blocks from 30 IRHD to 90 IRHD, calibrate IRHD pocket hardness meter. The set of standard rubber blocks is stored in a container with a suitable cover after being sprinkled with talc powder, in order to prevent the influences by light, heat, oil, or grease. It consists of at least 6 test pieces. These standard blocks must be calibrated with the international rubber hardness test specified in 4 at intervals not exceeding six months. It is advisable that the IRHD pocket hardness meter, which is used daily, is calibrated at least once a week with standard rubber block.

Remarks : When IRHD pocket hardness meter is calibrated with mechanical method or adjusted, the instruction manual issued by the manufacturer shall be depended.

6.3 Test piece

6.3.1 Shape and dimensions of test pieces The thickness of a test piece shall be 6 mm or more. When it is less than 6 mm, the test piece which was prepared by piling up to 6 mm or more can be used, but the number of piling up shall be 3 or less, and each of them shall have 2 mm or more thickness. The test result comes from piled test piece does not usually coincide with the test result by solid test piece(13). The lateral dimension of a test piece shall be large enough to measure at the point where the end point of an indentor is apart 12 mm or more from the edge of the test piece.

Test pieces shall have flat surface which is spacious to closely contact with the face of pressure foot of a hardness meter(16).

Note (16) The surface such as unsmoothed, curved, or rough, does not give satisfactory results. For specially formed surface, however, such as rubber roll, this method can be applied. In this case, the applicable limit of the IRHD pocket hardness meter shall be definitely confirmed.

6.3.2 Sampling and preparation of test pieces The sampling and preparation of test pieces shall follow **6.5** of **JIS K 6250**.

6.3.3 Selection of test pieces The test pieces which contain alien matters, bubbles, or flaws shall not be used for test.

6.4 Testing method

6.4.1 Testing conditions Testing conditions shall be as follows.

(1) The standard conditions of a laboratory shall follow **6.1** of **JIS K 6250**.

(2) Storing of sample and test pieces shall follow **6.2** of **JIS K 6250**.

(3) The standard conditions of test pieces shall follow **6.3** of **JIS K 6250**.

6.4.2 Procedures Place a test piece on a rigid, hard, and flat surface. Set an IRHD pocket hardness meter so as to make an indentor rectangular to the target surface of a test piece. Contact closely as swiftly as possible the face of pressure foot with the target surface of the test piece without giving a impact, and read the scale within 1 s, to find the hardness of the test piece. The end point of the indentor of an IRHD pocket hardness meter must be apart 12 mm or more from the edge of the test piece. Unless otherwise specified, read the value within 1 s after close contacting, but if the reading after special duration is specified, follow that specification. In this case, the duration from close contacting to the finish of reading shall be recorded. The measuring points shall be 5, which are apart at least 6 mm each other, and carry out measurements 5 times on these points.

6.5 Arrangement of test results Round off the median of 5 measurements to whole number according to **JIS Z 8401**, then mark sign IRHD after the value, and in case of standard hardness, after the value mark sign "/", then sign S, then again sign "/" and last sign P which means testing method. In case of apparent hardness, mark sign "/" after sign IRHD, then mark sign P which means testing method.

Example 1 50 IRHD/S/P: means that standard test piece is measured by IRHD pocket hardness meter, and the standard hardness is 50 IRHD.

Example 2 50 IRHD/P: means that nonstandard test piece is measured by IRHD pocket hardness meter, and the apparent hardness is 50 IRHD.

6.6 Record On test result, the following items shall be recorded.

(1) Test result

(2) Shape and dimensions of test piece (whether standard test piece or nonstandard test piece; in case of piled up test piece, the number of piled pieces, and its thickness)

(3) Sampling and preparation methods of test pieces

(4) Other items specially needed

Related standards :

ISO 7267/1 : 1986 *Rubber-covered rollers—Determination of apparent hardness—Part 1 : IRHD method*

ISO 7267/2 : 1986 *Rubber-covered rollers—Determination of apparent hardness—Part 2 : Shore-type durometer method*

Informative reference
International rubber hardness testing method for curved test piece

Introduction This Informative reference states the international rubber hardness testing method for curved test piece, and does not make a part of Standard.

1 Purpose This test shall be carried out to measure international rubber hardness degree of a test piece of vulcanized rubber whose target surface makes a curved surface. The measured values obtained by this method are always treated as an apparent hardness.

Remarks : The standards cited in this Informative reference are listed as follows.

ISO 48 : 1994 *Rubber, vulcanized or thermoplastic—Determination of hardness (hardness between 10 IRHD and 100 IRHD)*

ISO 7267/1 : 1986 *Rubber-covered rollers—Determination of apparent hardness—Part 1 : IRHD method*

ISO 7267/2 : 1986 *Rubber-covered rollers—Determination of apparent hardness—Part 2 : Shore-type durometer method*

2 Type of testing method

(1) CH method (normal size curved surface test for high hardness)

(2) CN method (normal size curved surface test for normal hardness)

(3) CM method (microsize curved surface test for normal hardness)

(4) CL method (normal size curved surface test for low hardness)

3 Scope CH method, CN method, CM method, and CL method are the modified H method, N method, M method, and L method for the purpose of making them applicable to the test piece whose target surface is curved, and there are the following two cases(1).

(1) Test piece or sample is large enough to place the hardness testing apparatus on it.

(2) Test piece or sample is so small that it must be placed on a holding base together with a hardness testing apparatus. The case where the sample is put on a flat sample base which makes one body with a testing apparatus, is included in this case.

Note (1) Generally, these tests are carried out directly on products, so that the thickness of rubber is not constant, and in many cases, the lateral distance from the end ball of a plunger to the edge of sample is smaller than the smallest distance shown in 4.4.3 in the body of this Standard, and the influence owing to the distance from the edge is not negligible.

Therefore, the measured values resulted from these methods don't coincide with the values obtained by the measurements of the plate-type test pieces with flat parallel surfaces and the same thickness as that of standard test pieces or products which are specified in H method, N method, M method and L method.

This means that, the results obtained by measuring curved surface are the peculiar measurements which are applicable only to the test pieces or the products having special shape and special dimensions and further being kept in special method. In extreme case, these measured values show discrepancy of 10 IRHD from the standard hardness. The measured values on the surface buffed to eliminate covered cloth or treated specially, shows a little difference value from the value on flat surface which has been finished with molding.

4 Testing apparatus

4.1 General matters Basically, testing apparatus follows **4.3** of the body of this Standard, but the following gives difference.

4.2 Testing apparatus for cylindrical surface of 50 mm or more radius As shown in Informative reference Fig. 1, the bottom base of the testing apparatus has a hole through which annular pressure foot can penetrate, for the measurement even when sample is put under the base.

There are two cylindrical surfaces which are parallel each other under the base, and these are parallel to the horizontal surface of the base. The diameter of these cylinders and the distance between them shall be suitable for setting up testing apparatus on the target curved surface of sample. Alternatively, the base, on which adjustable legs with universal joints are attached to comply with the target curved surface, may be used.

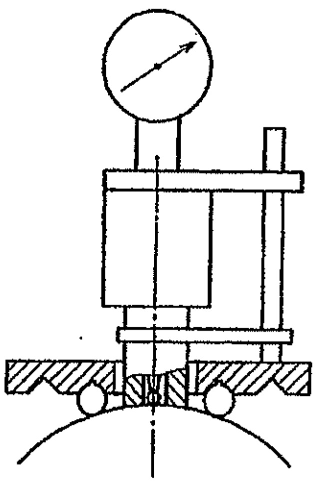
4.3 Testing apparatus for two-way curved surface of 50 mm or more radius The testing apparatus with adjustable legs with universal joints shown in **4.2** can be used.

4.4 Testing apparatus for cylindrical surface and two-way curved surface of 4 mm to 50 mm radius When target surface is too small to set a testing apparatus on it, as shown in Informative reference Fig. 2, fix test piece or sample using a special jig, V-block, or the like, and set the plunger to be perpendicular onto the target surface. When a small test piece is fixed on a sample table, wax may be used(2)(3).

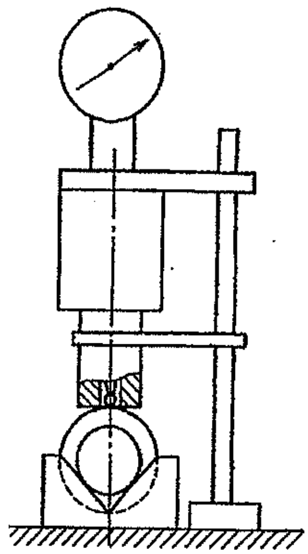
Notes (2) The testing apparatus for M method shall be generally used only for the test piece whose thickness is 4 mm or less.

(3) The testing apparatus for M method, whose sample table is forced up owing to the action of a spring, is not suitable for the large-sized test piece or sample having curved surface with large radius.

4.5 Testing apparatus for small type O-ring and curved sample of 4 mm or less radius In these cases, hold a test piece on the table of testing apparatus using a suitable jig, block, wax, or the like. Carry out measurement using a testing apparatus of M method. The test piece having the minimum radius of 0.8 mm or less cannot be measured.



Informative reference Fig. 1 Example of setting a testing apparatus for sample with large diameter



Informative reference Fig. 2 Example of setting a testing apparatus for sample with small diameter

5 Test pieces

5.1 General matters The test pieces for CH method, CN method, CM method, and CL method are the products or the pieces prepared by cutting the products. The bottom side of the test piece which has been cut out shall be held with suitable method. In case of the target surface is covered with cloth, it must be buffed before testing. In order to recover it from the influence by buffing, allow it to stand for 16 h or more under standard condition of laboratory, and then carry out conditioning under standard condition according to (3) of 4.5.1 in the body of this Standard. This duration may be included in the duration for recovering.

5.2 Sampling and preparation of test pieces The sampling and preparation of test pieces shall follow 4.4.4 in the body of this Standard.

5.3 Selection of test pieces The selection of test pieces shall follow 4.4.5 in the body of this Standard.

6 Testing method The testing method shall follow 4.5 in the body of this Standard.

7 Arrangement of test results Round off the median of 3 or 5 measurements to whole number according to **JIS Z 8401**, and then mark sign IRHD after the value. After that, mark sign "/", and then mark CH, CN, CM, or CL which means testing method.

Example : 50 IRHD/CM: means that a curved test piece is measured by CM method of international rubber hardness curved-surface test, and the hardness is 50 IRHD.

8 Record On test result, the following items shall be recorded.

(1) Test result

(2) Shape and dimensions of test pieces

(3) Sampling and preparation methods of test piece

(4) Test temperature

(5) Other items specially needed

EX-4

GOLF BALL TESTING PROTOCOLS
Bridgestone vs. Acushnet

GENERAL INSTRUCTIONS

Marking: For each golf ball and golf ball component to be tested, each golf ball and golf ball component should be identified by a testing serial number, using the coding system set forth previously (for example "P1.AA.01"). The "ZZ" code is to be the ball number code and numbering should start at "01". The "XX" code is to be the source code of the golf balls and will match the source code marked on the package of the purchased golf balls. This code will designate the source for the golf balls, i.e. their origin and/or retail outlet. A data file will contain the relevant purchase information for each source code.

Component Marking: During testing, each component of a golf ball which is removed from a golf ball (i.e. cover and intermediate layer) should bear the same serial number, by either marking or placarding. Therefore, at any time after the test has been completed, the tester, or any other individual, should be able to identify the components that came from each respective golf ball tested.

Limited Exposure: Once a golf ball core is exposed to the atmosphere (by removal of the cover or the intermediate layer), and/or when the core is cut, all hardness and compression testing on the core must be performed within 24 hours of exposure.

Storage of Samples: Once tested, all golf ball components and samples for each respective golf ball are to be stored in a sealed container separately for each golf ball, where the container bears the serial number identification for the golf ball located therein. Any and all sections of the core of each respective golf ball are to be stored in a sealed, evacuated container/package so as to limit exposure to the atmosphere. All golf balls and golf ball components are to be stored in an environmentally controlled environment at room temperature and normal atmospheric conditions.

Initial Testing Protocols: Prior to testing each golf ball, the following general instructions are to be followed:

1. Each golf ball to be tested is assigned a serial number, in the form shown above, which is recorded in a test data sheet. The serial number is to be marked or otherwise placarded on the ball so as to appear near the sidestamp of the golf ball, and so as to not be destroyed during testing.
    a. The golf ball is then to be photographed so as to record the sidestamp and assigned serial number.
    b. As components of the ball are removed for further testing (i.e. cover, intermediate layer and core), each of these respective components are to also be immediately marked or placarded with the same serial number of the ball from which they originated.
2. The name of the tester, date and time of the test, type of test, and room conditions (including temperature and humidity) of the test are to be recorded in a test log, which records such conditions for each test and each golf ball/ball component serial number.

GOLF BALL TESTING PROTOCOLS
Bridgestone vs. Acushnet

3. Each golf ball, prior to testing, is to be placed in a environmentally controlled room at room temperature and standard atmospheric conditions for at least 24 hours prior to testing to ensure that the ball and its respective components are all at an equilibrium state.
4. All test results are to be kept in a form (such as a data sheet) which allows easy determination of the test information, including golf ball tested (by sidestamp), test conditions, test time, tester, type of test being performed, golf ball/component serial number and test result for each golf ball/component tested.

Errors: Once testing is begun on a golf ball or component, that golf ball/component should not be purposefully disposed off. If errors are made during testing, the error should be noted and explained within the test data sheet, and the ball, with all of its components, archived as are all other balls, as explained above.

Calibration: Prior to testing, all measurement components and devices used in determining golf ball properties or material characteristics are to have its respective calibration verified. If calibration can not be verified the device must be calibrated in accordance with all manufacturer standards and requirements. All verification and/or calibration exercises are to be recorded so as to include: date and time of verification/calibration, person performing the verification/calibration and identification of the standards used. If a series of tests are to be performed in succession it is not necessary to calibrate/verify in between each test, unless the tester has reason to believe that the calibration of the device has been compromised in any way.

Low Supply Golf Balls: In the event that the inventory of golf balls does not permit a full compliment of testing as required in the attached protocols, separate protocols will be used for each of those balls, in which the quantities will be modified to ensure a complete line of testing is performed. Each of those protocols will exist separately for those respective balls.

Randomly Selected Balls: Unless otherwise specified, all golf balls selected for testing are to be selected randomly. No more than four (4) golf balls can be selected from any one dozen package of golf balls, for a given test at one time. However, if the number of available balls are limited, more than four (4) golf balls may need to be used from a single package. If more than four (4) golf balls are used from a single package, it should be noted along with an explanation along with the method of selection employed, which must be as random as possible.

GOLF BALL TESTING PROTOCOLS
Bridgestone vs. Acushnet

Ball Codes for Testing Serial Numbers
Core-Sidestamp Correlations

Brand	Name	Sidestamp	Core Color	Testing Prefix
Titleist	Pro V1	Pro V1 392 *	Violet	P1.XX.ZZ
		◀Pro V1•392▶	Violet	P2.XX.ZZ
		◀•Pro V1 392•▶	Dark Blue	P3.XX.ZZ
		◀Pro V1-392▶	Green	P4.XX.ZZ
	Pro V1*	◀Pro V1* 392▶	Yellow/Blue	PS.XX.ZZ
	Pro V1x	◀•Pro V1x 332•▶	Orange/Blue	PX1.XX.ZZ
		◀Pro V1x-332▶	Dark Rd/Gray	PX2.XX.ZZ
	NXT	◀NXT▶	Dark Red	N1.XX.ZZ
		◀-NXT-▶	Red	N2.XX.ZZ
	NXT Tour	◀NXT•Tour▶	Royal Blue	NT1.XX.ZZ
		◀NXT Tour▶	Dark Green	NT2.XX.ZZ
		◀NXT-Tour▶	Black/Yellow	NT3.XX.ZZ
	DT So/Lo	DT So/Lo	Dark Orange	D1.XX.ZZ
		◀DT So/Lo▶	Aqua Blue	D2.XX.ZZ
Pinnacle	Exception	Pinnacle Exception	Light Green	E1.XX.ZZ
		Pinnacle	Light Blue	E2.XX.ZZ

* Sidestamp "Pro V1 392" in the table above includes both versions of the Pro V1 golf ball bearing the sidestamp "Pro V1 392", Pro V1 392 and Pro V1 392 (stretched).

EX-9

GOLF BALL TESTING PROTOCOLS
Bridgestone vs. Acushnet

Protocol for Core Hardness and Diameter Measurements

This protocol describes the steps to be taken for accurately measuring the hardness at different locations on and inside of the golf ball core. The core hardness test method is in accordance with JIS K6301 – Physical Testing Methods for Testing Vulcanized Rubbers and JIS K6253 – Hardness Testing Methods for Rubber, Vulcanized or Thermoplastic, copies of which are attached as Exhibits C and D, unless otherwise specified.

CORE DIAMETER

BALLS: Pro V1, Pro V1x, Pro V1*, NXT, NXT Tour, DT So/Lo, and Exception

1. Randomly select golf balls of a single type and record all required information as set forth in the GENERAL INSTRUCTIONS.

2. Remove the outer cover and intermediate layers (if present) of the golf ball by using a side cutter. The cutting tool should be advanced into the ball at small increments to ensure that the core is not scarred or scarring is at a minimum.

   a. Prior to cutting remove the cover, refer to photographs of the subject golf ball specimen sectioned in half, or a data chart, to determine the core color, and ball structure. This will notify operator of a possible intermediate layer, and aid in identifying when the operator is close to the core surface.

   b. NOTE: All Pro V1, Pro V1x and Pro V1* golf balls will have a clear intermediate layer before the core. All NXT, NXT Tour, DT So/Lo and Pinnacle Exception golf balls will only have a cover before the core.

3. Manually peel the cover and intermediate layer, if present, of the golf ball to expose the solid core.

   ONCE THE CORE IS EXPOSED ALL OF THE FOLLOWING HARDNESS TESTING FOR THE CORE SURFACE MUST BE COMPLETED WITHIN 24 HOURS.

4. Mark or placard each of the separated components (core, cover and intermediate layer) with the serial number of the golf ball. Place each of the marked or placarded cover and intermediate layer sections in individual packaging marked with the ball serial number.

5. Closely examine the core surface adjacent to the cutting tool path to determine if the core surface was scarred or otherwise nicked by the cutting tool.

   a. No testing of the core surface hardness can take place within 20 degrees of the surface scarring.

6. Using a digital height gauge measure and record the outermost diameter of the core at five (5) randomly selected core orientations, not within 30 degrees of each other. Further, the core diameter measurement cannot take place where the core has been nicked or scarred.

   a. Prior to making any measurements, the accuracy of the height gauge must be verified using a certified gauge block.

7. Using the determined average core diameter of each core calculate the standard deviation of the averages.

CORE SURFACE HARDNESS

This test is required to be performed on all NXT, NXT Tour, DT So/Lo, Pinnacle Exception and Pro V1 golf balls. The core hardness test method is in accordance with JIS K6301 – Physical Testing Methods for Testing Vulcanized Rubbers and JIS K6253 – Hardness Testing Methods for Rubber, Vulcanized or Thermoplastic, unless otherwise specified.

BALLS: Pro V1, Pro V1x, Pro V1*, NXT, DT So/Lo, and Exception

8. Verify hardness tester accuracy by performing hardness testing on calibration block.

   a. Hardness results performed on the calibration block must be within the limits specified on the calibration block.

   b. If the machine is not in calibration do not continue.

9. Perform hardness measurements in the JIS C hardness scale at five (5) locations on the surface of the ball. Each of the five points are to be randomly selected and are to be marked to identify the location of the hardness test. The hardness measurement points must not be within 20 degrees of each other, and are not to have any scarring or nicks. Further, at each of the five locations five (5) individual and discrete measurements are to be taken.

   a. The JIS C testing should be in accordance with the JIS K6301 standards. It is recognized that the core is a round surface, however, this deviation from the hardness standard is acceptable.

   b. Confirm the highest point of the core is the point that is being tested. The presser foot of the indenter must not contact the core's surface until the indenter is completely immerged into the material.

c. The locations of the hardness measurement points are to be selected taking into account the protocol set forth below regarding testing at 5 mm within the surface of the core, so as to minimize the number of measurement points which are permanently lost when that protocol is performed.

10. Record each individual measurement in a data table and calculate an average for each of the five locations tested. Using these five averages calculate a core surface hardness average. Record the averages in the data table.

11. Using the determined average hardness at the surface of each core calculate the standard deviation of the averages.

HARDNESS AT 5MM WITHIN THE SURFACE OF THE CORE

This test is only required to be performed on NXT, DT So/Lo and Pinnacle Exception golf balls, and is not to be performed on any Pro V1 golf balls. The core hardness test method is in accordance with JIS K6301 – Physical Testing Methods for Testing Vulcanized Rubbers and JIS K6253 – Hardness Testing Methods for Rubber, Vulcanized or Thermoplastic, unless otherwise specified.

BALLS: NXT, DT So/Lo, and Exception

12. Remove cover in accordance with Steps 2 and 3 above.

13. Select a portion of the core to be tested, preferably not resulting in the removal or discarding any core surface hardness testing locations.

14. Machine gripping surfaces or slots in the core opposite from the selected portion of the core to be tested, as described in other testing protocols so as to allow for the secure gripping of the core.

15. Use a band saw to cut off the selected portion of the core (selected in Step 12) at a point at least 8 mm from the surface of the core, so as to create a specimen which is at least 8 mm in thickness at its deepest point.

    a. Store the remaining core section in a sealed, evacuated container/package so as to limit exposure to the atmosphere, and place with the remaining ball components from the golf ball tested.

16. Secure the specimen created in Step 14 in a Bridgeport, or comparable, end-mill device in such a way to ensure the specimen is secure while minimizing squeezing and distorting the specimen. The specimen is to be secured such that the surface cut by the band saw is facing the end-mill tooling (i.e. curved surface away), and the surface is level.

GOLF BALL TESTING PROTOCOLS
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ONCE THE FOLLOWING MACHINING PROCESS BEGINS ALL OF THE FOLLOWING HARDNESS PROTOCOL FOR 5 MM WITHIN THE CORE SURFACE MUST BE COMPLETED WITHIN 24 HOURS.

17. Using the Bridgeport, or comparable, end-mill machine, machine off the cut surface of the specimen in multiple passes. The depth of each pass is to minimal such that the specimen is not destroyed during the process or dislodged from the end-mill gripping vise.

    a. A cutting head and cutting speed must be used to minimize burrs and heat generation during the machining process.

    b. At least 10 seconds should elapse between each machining pass to allow for heat dissipation.

18. The amount of material to be removed is to result with a test specimen which is 5 mm thick at its thickest point.

    a. As the 5 mm limit is approached the depth of each pass is to be reduced to a depth of no more than 0.05 mm. This will ensure minimal damage and scarring to the surface of the specimen.

    b. At least 10 seconds should elapse between each machining pass to allow for heat dissipation.

    c. The tolerance of the thickness of the specimen, at its thickest point is 5 mm +/- 0.2 mm. If the amount of removed material is within this tolerance, the test may proceed.

19. Inspect the machined surface of the test specimen. If the surface is smooth testing may proceed. If the test surface is not smooth it is to be hand buffed to provide a smooth surface.

20. Record the height of the test specimen.

    a. The tolerance of the 5 mm thickness is +/- 0.2 mm. If the amount of removed material is within this tolerance, the test may proceed.

    b. If the test specimen is not within this tolerance, but is within an additional +/- 0.2 mm, the specimen may be tested but its non-compliance with the above tolerance is to be recorded.

    c. Locate and identify the center of the machined surface.

21. Verify hardness tester accuracy by performing hardness testing on calibration block.

a. Hardness results performed on the calibration block must be within the limits specified on the calibration block.

b. If the machine is not in calibration do not continue, and calibrate machine accordingly.

22. Perform hardness test in accordance with JIS C standard at the center of the machined surfaces. Five (5) separate and discrete tests are to be done at the center of each of the machined surfaces.

23. Record each of the (five) 5 measurements, for each side, and determine and record an average of the (five) 5 measurements, for each side. Each data point is to be recorded.

24. Determine and record a core hardness average by calculating an average based on the averages from each respective milled surfaces.

25. Store the tested specimen in a sealed, evacuated container/package so as to limit exposure to the atmosphere, and place with the remaining ball components from the golf ball tested.

26. Using the determined average hardness at 5 mm within the surface of each core calculate the standard deviation of the averages.

CORE CENTER HARDNESS:

This test is required to be performed on all NXT, DT So/Lo, Pinnacle Exception and Pro V1 golf balls. The core hardness test method is in accordance with JIS K6301 – Physical Testing Methods for Testing Vulcanized Rubbers and JIS K6253 – Hardness Testing Methods for Rubber, Vulcanized or Thermoplastic, unless otherwise specified.

BALLS: Pro V1, Pro V1x, Pro V1*, NXT, DT So/Lo, and Exception

27. Repeat Steps 1 through 6 above on randomly selected golf balls; OR

a. For NXT, NXT Tour, DT So/Lo and Pinnacle Exception golf balls, it is possible to use the twelve (12) cores from Steps 1-11.[1]

ONCE THE FOLLOWING MACHINING PROCESS BEGINS ALL OF THE FOLLOWING HARDNESS PROTOCOL FOR CORE CENTER HARDNESS MUST BE COMPLETED WITHIN 24 HOURS.

[1] For Pro V1 model golf balls the protocol for Core Hardness Distribution may be conducted first, followed by the protocol for measuring core center hardness.

28. Using the Bridgeport, or comparable, end-mill machine, machine off the section of the core selected for removal to a depth within 0.3 to 0.4 mm above the calculated center of the core.

    a. The entire depth of removed material should not be machined off in one pass, but a plurality of passes not exceeding a depth of 1 mm is to be used.

    b. A cutting head and cutting speed must be used to minimize burrs and heat generation during the machining process.

    c. At least 10 seconds should elapse between each machining pass to allow for heat dissipation.

29. To reach the final depth of the core center, the machined surface is to be buffed with no GREATER than 220 grit sandpaper, or comparable abrasive, to provide smooth surface free of machining marks and/or grooves. The buffing step must be done at a slow speed to minimize heat generation at the surface of the core, and a depth of no more than 0.05 mm for any one pass.

    a. At least 10 seconds should elapse between each machining pass to allow for heat dissipation.

30. Locate and identify the center of the machined surface.

31. Record the new ball diameter.

32. The tolerance of the center of the core is +/- 0.2 mm. If the amount of removed material is within this tolerance, the test may proceed.

33. Verify hardness tester accuracy by performing hardness testing on calibration block.

    a. Hardness results performed on the calibration block must be within the limits specified on the calibration block.

    b. If the machine is not in calibration do not continue, and calibrate machine accordingly.

34. Perform hardness test in accordance with JIS C standard at the center of the machined surface. Five (5) separate and discrete tests are to be done at the center of the machined surface.

35. Record each of the (five) 5 measurements and determine and record an average of the (five) 5 measurements.

36. Store the remaining core section in a sealed, evacuated container/package so as to limit exposure to the atmosphere, and place with the remaining ball components from the golf ball tested.

    a. The cores of the Pro V1 model golf balls may be used in the following protocol for CORE HARDNESS DISTRIBUTION. If this is done the CORE HARDNESS DISTRIBUTION test must be done within 24 hours of exposure of the center of the core.

37. Using the determined average hardness at the center of the core calculate the standard deviation of the averages.

CORE HARDNESS GRADIENT:

This test is required to be performed on all Pro V1 and Pro V1x[2] model golf balls and is not to be performed on any of the NXT, NXT Tour, DT So/Lo, and Pinnacle Exception golf balls. The core hardness test method is in accordance with JIS K6301 – Physical Testing Methods for Testing Vulcanized Rubbers and JIS K6253 – Hardness Testing Methods for Rubber, Vulcanized or Thermoplastic, unless otherwise specified.

BALLS: Pro V1 and Pro V1x

PRO V1

38. For **Pro V1** model golf balls, using the calculated diameter of the core from Steps 1 through 6, calculate the core radius and divide the radius into three (3) equidistant sections, which identifies two (2) evenly spaced points between the core center and the core surface along a single radial line to the surface.

    a. Record the core radius and measurement for the equidistant sections.

    b. Each of the evenly spaced points represent measurement depths for the core hardness distribution. The outermost point is the first measurement depth and the innermost point (not the center) is the second measurement point.

39. The core surface hardness is to be measured and recorded in accordance with the Core Surface Hardness protocol, set forth above.

40. Select a portion of the core to be removed, and mark the surface of the core.

41. Mount the core on a platen surface of a Bridgeport, or comparable, end-mill machine, using a mounting structure which minimizes squeeze of the core, while maintaining the core in a fixed position. The area marked in Step 40 shall be facing vertically and represent the highest point on the core's circumference.

[2] The protocol for the Pro V1x is different from that of the Pro V1, as set forth herein.

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ONCE THE FOLLOWING MACHINING PROCESS BEGINS ALL OF THE FOLLOWING HARDNESS PROTOCOL MUST BE COMPLETED WITHIN 24 HOURS.

42. Using the Bridgeport, or comparable, end-mill machine, machine off the section of the core selected for removal to a depth of 0.3 to 0.4 mm above the first measurement depth of the core.

    a. The entire depth should not be machined off in one pass, but a plurality of passes in which a set depth of material is removed in each pass. As the desired cut depth approaches each pass should not exceed a depth of more than 1 mm to ensure accuracy.

    b. A cutting head and cutting speed must be used to minimize burrs and heat generation during the machining process.

    c. At least 10 seconds should elapse between each machining pass to allow for heat dissipation.

43. To reach the final depth of the first measurement depth, the machined surface is to be buffed with no GREATER than 220 grit sandpaper, or comparable abrasive, to provide smooth surface free of machining marks and/or grooves. The buffing step must be done at a slow speed to minimize heat generation at the surface of the core, and a depth of no more than 0.05 mm for any one pass.

    a. At least 10 seconds should elapse between each machining pass to allow for heat dissipation.

44. Locate and identify the center of the first measurement surface and mark the center

45. Record the new ball diameter.

    a. The tolerance of the first measurement surface is +/- 0.2 mm. If the amount of material removed is within this tolerance, the test may proceed.

46. At a position 180 degrees from the first measurement surface, create the second measurement surface (from the results in Step 38b) repeating Steps 42 through 44 above.

47. Locate and identify the center of the second measurement surface and mark the center.

48. Record the new ball diameter.

    a. The tolerance of the second measurement surface is +/- 0.2 mm. If the amount of material removed is within this tolerance, the test may proceed.

49. Verify hardness tester accuracy by performing hardness testing on calibration block.

    a. Hardness results performed on the calibration block must be within the limits specified on the calibration block.

    b. If the machine is not in calibration do not continue, and calibrate machine accordingly.

50. Perform hardness test in accordance with JIS C standard at the center of the two machined measurement surfaces. Five (5) separate and discrete tests are to be done at the center of the machined surface.

51. Record each of the five (5) measurements and determine and record an average of the (five) 5 measurements.

52. If the core center hardness is to be determined, proceed to the Core Center Hardness protocol and complete the core center hardness test.

53. Using the determined average hardness on each of the measurement surfaces, calculate the standard deviation of the averages for each of the respective measurement surfaces.

PRO V1x

54. For **Pro V1x** model golf balls, using the calculated diameter of the core from Steps 1 through 6, calculate the core radius.

    a. Record the core radius.

    b. For the purposes of measuring the hardness distribution of the Pro V1x golf balls, the depths of measurement are laid out below:

        i. First measurement depth is 3.5 mm from the core surface.

        ii. Second measurement depth is at the surface of the center portion of the core (i.e. gray color portion in model ◀ Pro V1x-332 ▶ and blue color portion in model ◀•Pro V1x 332•▶).[3]

        iii. Third measurement depth is at 6.4 mm below the second measurement depth.

[3] The target diameter of the core is 1.55 inches whereas the target diameter of the inner portion of the core is 1.0 inches. Accordingly, the third measurement depth is approximately 7.0 mm below the surface of the core.

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iv. Fourth measurement depth is at the center of the inner portion of the core, determined based on the calculated radius of the core.

55. The core surface hardness is to be measured and recorded in accordance with the Core Surface Hardness protocol, set forth above.

56. Select a portion of the core to be removed, and mark the surface of the core.

57. Mount the core on a platen surface of a Bridgeport, or comparable, end-mill machine, using a mounting structure which minimizes squeeze of the core, while maintaining the core in a fixed position. The area marked in Step 56 shall be facing vertically and represent the highest point on the core's circumference.

ONCE THE FOLLOWING MACHINING PROCESS BEGINS ALL OF THE FOLLOWING HARDNESS PROTOCOL MUST BE COMPLETED WITHIN 24 HOURS.

58. Using the Bridgeport, or comparable, end-mill machine, machine off the section of the core selected for removal to a depth of 0.3 to 0.4 mm above the first measurement depth of the core.

    a. The entire depth should not be machined off in one pass, but a plurality of passes in which a set depth of material is removed in each pass. As the desired cut depth approaches each pass should not exceed a depth of more than 1 mm to ensure accuracy.

    b. A cutting head and cutting speed must be used to minimize burrs and heat generation during the machining process.

    c. At least 10 seconds should elapse between each machining pass to allow for heat dissipation.

59. To reach the final depth of the first measurement depth, the machined surface is to be buffed with no GREATER than 220 grit sandpaper, or comparable abrasive, to provide smooth surface free of machining marks and/or grooves. The buffing step must be done at a slow speed to minimize heat generation at the surface of the core, and a depth of no more than 0.05 mm for any one pass.

    a. At least 10 seconds should elapse between each machining pass to allow for heat dissipation.

60. Locate and identify the center of the first measurement surface and mark the center.

61. Record the new ball diameter.

a. The tolerance of the first measurement surface is +/- 0.2 mm. If the amount of material removed is within this tolerance, the test may proceed.

62. At a position 180 degrees from the first measurement surface, create the second measurement surface repeating Steps 58 through 59 above.

63. Locate and identify the center of the second measurement surface and mark the center.

64. Record the new ball diameter.

    a. The tolerance of the second measurement surface is +/- 0.1 mm. If the amount of material removed is within this tolerance, the test may proceed.

65. Verify hardness tester accuracy by performing hardness testing on calibration block.

    a. Hardness results performed on the calibration block must be within the limits specified on the calibration block.

    b. If the machine is not in calibration do not continue, and calibrate machine accordingly.

66. Perform hardness test in accordance with JIS C standard at the center of the first two measurement surfaces. Five (5) separate and discrete tests are to be done at the center of the machined surface.

67. Record each of the (five) 5 measurements and determine and record an average of the (five) 5 measurements.

68. Machine the second measurement surface to the third measurement surface following the same procedures set forth above in Steps 58 - 61.

69. Perform hardness test in accordance with JIS C standard at the center of the machined surface of the third measurement surface. Five (5) separate and discrete tests are to be done at the center of the machined surface.

70. Record each of the (five) 5 measurements and determine and record an average of the (five) 5 measurements.

71. For the fourth measurement surface (core center hardness), proceed to the Core Center Hardness protocol and complete the core center hardness test.

72. Using the determined average hardness on each of the measurement surfaces, calculate the standard deviation of the averages for each of the respective measurement surfaces.

EX-10

GOLF BALL TESTING PROTOCOLS
Bridgestone vs. Acushnet

Protocol for Intermediate Layer Hardness Measurements

This protocol describes the steps to be taken for accurately evaluating the hardness of the intermediate layer of a golf ball.

As a general matter the "GENERAL INSTRUCTIONS" of the Bridgestone v. Acushnet testing protocols are to be followed for the preparation, storage, and data tracking for the following test procedures.

BALLS: Pro V1, Pro V1x, and Pro V1* (star)

To remove outer layers and expose the intermediate layers (IMLs), see the procedures set forth in the Protocol for Core Hardness and Diameter.

1. Randomly select a number of golf balls from which the IMLs will be tested.
   a. NOTE: Intermediate layers from golf balls that have been used in other tests is acceptable. It is not necessary that new golf balls be used for this test protocol. IMLs from previously tested balls are to be tracked appropriately.
2. On new balls, use a side cutter to cut the cover and intermediate layer on the golf ball into four (4) approximately equal sized pieces.
3. Remove the cover and IML as a unit from the golf ball core.
4. Separate the cover from IML.
5. Using a grinding device, such as a Dremel tool, and a steel grinding stone, grind both sides of the IML to remove any residue left behind by either the cover material or the core material.
   a. NOTE: The grinding should be minimal so as to merely remove any residue of the cover or core.
6. Cut each of the four (4) pieces of the IML into circular disks with an approximate diameter of 1.25 inches.
7. In a compression molding machine, using a temperature controlled resistance heater, pre-heat compression molding platens and press for 30 minutes at 290°F.
   a. The compression molding platens are to be of sufficient size to be used on the disks cut above in Step 6.
8. Place and stack approximately 6 grams of material (between eight (8) and twelve (12) pieces) of the cut IML pieces into the compression molding machine and allow the IML pieces to pre-heat within the machine at 290°F for 15 minutes.
9. After the 15 minute pre-heat of Step 8, increase pressure within the pressure molding machine to 5,000 lbs of force. Ramp up time for the pressure is to be approximately one (1) minute.

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Bridgestone vs. Acushnet

10. Hold heat (290°F) and pressure (5,000 lbs) constant for a minimum of 10 minutes.

11. Remove heat from the compression molding platens, and cool the machine and platens using aluminum heat exchange cylinders, or the like.
    a. NOTE: To increase the cooling rate, the aluminum cylinders should be continuously replaced with a cooler unit.

12. After cooling, allow the molded test sample to "cure" for ten (10) days.
    a. NOTE: To minimize moisture absorption the test plaque should be placed in a desiccant.

13. Inspect the test plaque to ensure no air bubbles, gaps, or foreign materials are present within the plaque.

14. Verify the accuracy of the hardness tester to be used (both Shore D and JIS-C), in accordance with the guidelines of the testing machine (using the required testing block).
    a. Ensure that the machine is properly calibrated in accordance with the guidelines and stated tolerances.
    b. If machine is outside of acceptable tolerances, calibrate and correct machine.

15. Perform both Shore D and JIS-C hardness on the test plaque and record the results.
    a. Prior to testing, ensure the test plaques are flat and level.
    b. If test plaques are not flat and level, the plaques must be surface ground using sandpaper.
    c. All test locations are to be at least 12 mm from the edge of the test plaque and at least 6 mm from each other.
    d. Perform two (2) Shore D hardness tests on each side of the plaque, and record each result (i.e. four (4) tests).
    e. Perform two (2) JIS-C hardness tests on each side of the plaque, and record each result (i.e. four (4) tests).

16. Determine an average hardness in both Shore D and JIS-C for each plaque tested.

EX-11

GOLF BALL TESTING PROTOCOLS
Bridgestone vs. Acushnet

Protocol for Cover Hardness (Acushnet Prepared Plaques)

This protocol describes the steps to be taken for accurately evaluating the hardness of the cover material of a golf ball, when the cover material is preformed into a test plaque.

As a general matter the "GENERAL INSTRUCTIONS" of the Bridgestone v. Acushnet testing protocols are to be followed for the preparation, storage, and data tracking for the following test procedures.

BALLS: NXT Tour, NXT and DT Solo

For the purposes of this test, the test plaques were produced by Acushnet Company during discovery.

1. Inspect the test plaque to ensure that a smooth surface is present.
2. Verify the accuracy of the hardness tester to be used (both Shore D and JIS-C), in accordance with the guidelines of the testing machine (using the required testing block).
   a. Ensure that the machine is properly calibrated in accordance with the guidelines and stated tolerances.
   b. If machine is outside of acceptable tolerances, calibrate and correct machine.
3. Perform both Shore D and JIS-C hardness on the test plaque and record the results.
   a. Prior to testing, ensure the test plaques are flat and level.
   b. If test plaques are not flat and level, the plaques must be surface ground using sandpaper.
   c. All test locations are to be at least 12 mm from the edge of the test plaque and at least 6 mm from each other.
   d. Perform three (3) Shore D hardness tests on each side of the plaque, and record each result (i.e. six (6) tests).
   e. Perform three (3) JIS-C hardness tests on each side of the plaque, and record each result (i.e. six (6) tests).
   f. NOTE: On one side of the test plaques (four) 4 circular indentations are located, do not test hardness within these indentations.
4. Determine an average hardness in both Shore D and JIS-C for each plaque tested.

EX-12

GOLF BALL TESTING PROTOCOLS
Bridgestone vs. Acushnet

Protocol for Cover Layer Hardness Measurements (Packer Engineering Prepared Plaques)

This protocol describes the steps to be taken for accurately evaluating the hardness of the cover layer of a golf ball.

As a general matter the "GENERAL INSTRUCTIONS" of the Bridgestone v. Acushnet testing protocols are to be followed for the preparation, storage, and data tracking for the following test procedures.

BALLS: Pinnacle Exception, NXT Tour, NXT and DT Solo

To remove cover layers, see the procedures set forth in the Protocol for Core Hardness and Diameter.

1. Randomly select a number of golf balls from which the covers will be tested.
   a. NOTE: Cover layers from golf balls that have been used in other tests are acceptable. It is not necessary that new golf balls be used for this test protocol. Cover layers from previously tested balls are to be tracked appropriately.
2. On new balls, use a side cutter to cut the cover on the golf ball into four (4) approximately equal sized pieces.
3. Remove the cover as a unit from the golf ball core.
4. Using a grinding device, such as a Dremel tool and a steel grinding stone, grind both sides of the Cover to remove all dimples, paint and any residue left behind by the core material.
   a. NOTE: The grinding should be minimal so as to merely remove any dimples, paint and residue of the core.
5. Cut each of the four (4) pieces of the cover into circular disks with an approximate diameter of 1.25 inches.
6. In a compression molding machine, using a temperature controlled resistance heater, pre-heat compression molding platens and press for 30 minutes at 290°F.
   a. The compression molding platens are to be of sufficient size to be used on the disks cut above in Step 6.
7. Place and stack approximately 6 grams of material (between eight (8) and twelve (12) pieces) of the cut cover pieces into the compression molding machine and allows the cover pieces to pre-heat within the machine at 290°F for 15 minutes.
8. After the 15 minute pre-heat of Step 8, increase pressure within the pressure molding machine to 5,000 lbs of force. Ramp up time for the pressure is to be approximately one (1) minute.
9. Hold heat (290°F) and pressure (5,000 lbs) constant for a minimum of 10 minutes.

GOLF BALL TESTING PROTOCOLS
Bridgestone vs. Acushnet

10. Remove heat from the compression molding platens, and cool the machine and platens using aluminum heat exchange cylinders, or the like.
    a. NOTE: To increase the cooling rate, the aluminum cylinders should be continuously replaced with a cooler unit.
11. After cooling, allow the molded test sample to "cure" for ten (10) days.
    a. NOTE: To minimize moisture absorption the test plaque should be placed in a desiccant.
12. Inspect the test plaque to ensure no air bubbles, gaps, or foreign materials are present within the plaque.
13. Verify the accuracy of the hardness tester to be used (both Shore D and JIS-C), in accordance with the guidelines of the testing machine (using the required testing block).
    a. Ensure that the machine is properly calibrated in accordance with the guidelines and stated tolerances.
    b. If machine is outside of acceptable tolerances, calibrate and correct machine.
14. Perform both Shore D and JIS-C hardness on the test plaque and record the results.
    a. Prior to testing, ensure the test plaques are flat and level.
    b. If test plaques are not flat and level, the plaques must be surface ground using sandpaper.
    c. All test locations are to be at least 12 mm from the edge of the test plaque and at least 6 mm from each other.
    d. Perform two (2) Shore D hardness tests on each side of the plaque, and record each result (i.e. four (4) tests).
    e. Perform two (2) JIS-C hardness tests on each side of the plaque, and record each result (i.e. four (4) tests).
15. Determine an average hardness in both Shore D and JIS-C for each plaque tested.

EX-18

TABLE VI
CORE HARDNESS RESULTS (JIS C)
Pro V1, Pro V1 Star, NXT, DT So/Lo and Pinnacle Exception

Ball Model		Surface (JIS C)	Within 5mm of Core Surface (JIS C)	Difference - Surface and 5mm (JIS C)	Core Center (JIS C)
P2	Average	82.8			63.3
	Standard Deviation	1.06			1.41
	Minimum	81.4			61.4
	Maximum	84.2			65.2
PS	Average	86.8			
	Standard Deviation	1.13			
	Minimum	85.0			
	Maximum	90.2			
N2	Average	81.8	77.3	5.4	60.4
	Standard Deviation	1.10	0.85	0.88	1.55
	Minimum	79.4	74.6	4.0	56.4
	Maximum	84.8	79.0	7.2	64.0
N1	Average	83.2			61.7
	Standard Deviation	0.74			1.29
	Minimum	82.0			59.6
	Maximum	85.0			64.2
D2	Average	82.1	78.4	5.5	61.8
	Standard Deviation	3.39	1.49	1.16	1.38
	Minimum	71.4	74.0	2.0	58.8
	Maximum	86.6	79.4	6.8	65.0
D1	Average	85.3			63.1
	Standard Deviation	0.33			1.67
	Minimum	84.6			59.4
	Maximum	86.0			66.4
E2	Average	79.1	78.9	4.6	61.0
	Standard Deviation	3.21	1.77	1.35	1.29
	Minimum	72.8	74.2	1.2	59.0
	Maximum	83.0	80.2	6.2	64.2
E1	Average	83.9	79.0	5.0	61.9
	Standard Deviation	1.01	0.56	0.64	1.41
	Minimum	82.0	78.0	3.2	58.6
	Maximum	85.6	80.0	6.0	65.0

EX-21

TABLE IX

INTERMEDIATE LAYER (IML) HARDNESS RESULTS
(Packer Engineering Prepared Plaques)
Pro V1x, Pro V1 and Pro V1 Star

BALL MODEL		IML Hardness (SHORE D)	IML Hardness (JIS C)
PX2	Average	69.3	94.1
	Standard Deviation	0.85	0.70
	Minimum	67.8	92.8
	Maximum	70.3	95.0
PX1	Average	70.3	94.6
	Standard Deviation	0.52	0.52
	Minimum	69.8	94.0
	Maximum	70.8	95.0
P4	Average	70.4	94.3
	Standard Deviation	0.99	0.40
	Minimum	68.5	93.8
	Maximum	71.5	94.8
P3	Average	69.6	94.4
	Standard Deviation	0.29	0.88
	Minimum	69.3	93.5
	Maximum	69.8	95.3
PS	Average	69.1	93.7
	Standard Deviation	0.63	0.90
	Minimum	68.3	92.5
	Maximum	69.8	94.5

EXHIBIT 16

REDACTED

EXHIBIT 17

REDACTED

EXHIBIT 18

REDACTED